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Facies Analysis, Diagenetic Features and Depositional Environment of the Kometan Formation from Northeastern Iraq

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Abstract

This study involves microfacies analysis of the Kometan Formation from northeastern Iraq supported by detailed petrographic investigation for the main components and diagenetic processes using a petrographic microscope, scanning electron microscope (SEM), and X-Ray diffraction (XRD). The techniques have revealed that the formation includes two microfacies; lime wackestone and lime packstone microfacies which in turn are subdivided into seven sub-microfacies, that were deposited in the quiet and deep marine environment. Planktonic foraminifera (keeled and globular chamber types) are dominant, along with oligostegina in addition to subordinate benthonic foraminifera and fine-grained bioclasts. Calcite forms the main mineralogical composition in euhedral (rhombohedral), microcrystals, star-shaped, and columnar crystals in addition to pyrite and glauconite. All components are embedded in the micritic groundmass. The main diagenetic processes affecting the studied rocks include; chemical compaction (stylolite formation), dissolution, recrystallization, and cementation.

Keywords: Cretaceous, Diagenesis, Depositional Environment, Kometan, Microfacies, Northeastern Iraq.

التحليل السحني، الظواهر التحويرية والظروف الترسيبية لتكوين كوميتان من شمال شرقي العراق

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الخلاصة

اشتملت الدراسة الحالية على التحليل السحني لتكوين كوميتان من شمال شرقي العراق بوساطة الوصف البتروغرافي المفصل للمكونات الرئيسية والعمليات التحويرية باستخدام المجهر البتروغرافي والمجهر الماسح

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الالكتروني مع الاستعانة بتحليل حيود الاشعة السينية. اظهرت الدراسة بان التكوين يتألف من سحنتين دقيقتين هما سحنة الحجر الجيري الواكي وسحنة الحجر الجيري المرصوص والتي بدورهما قسمت الى سبعة سحنات ثانوية دقيقة والمترسبة في بيئة بحرية عميقة وهادئة. الفورامنيفرا الطافية (من نوع الكروية والجؤجؤية) هي الشائعة مع الاوليجوستيجاينا بالاضافة الى كميات اقل من الفورامنيفيرا القاعية والفتاتات العضوية الناعمة. يشكل الكالسايت اهم المكونات المعدنية وباشكال عدة: المنتظم المعيني السطوح، والناعم التبلور والشكل النجمي العمودي الشكل بالاضافة الى البايرايت والكلوكونايت. وهذه المكونات عموما مطمورة في ارضية ميكرايتية. من اهم العمليات التحويرية المؤثرة على صخور التكوين هي الانضغاط الكيمياوي (تكون الستايلولايت)، الاذابة، اعادة التبلور والسمنتة.

11. Introduction

The Upper Cretaceous (Upper Turonian–Lower Campanian) Kometan Formation is one of the widespread formations in northern and northeastern Iraq and also was penetrated in several wells in North Iraqi oilfields [1-2]. The Kometan Formation forms the lower part of the AP9 (Late Turonian–Danian) Arabian Plate Tectonostratigraphic Megasequence [3].

The formation is also regarded as one of the upper Cretaceous fractured carbonate petroleum reservoirs in northern Iraq and contributed to the formation of the huge oil fields situated in the western areas of the Zagros foreland basin, including Hamren, Taq Taq, Khabaz, Jambur, Kirkuk, and Bi Hassan oil fields [4].

The Kometan Formation is a part of the Turonian-Lower Campanian sub-cycle and widely crops out in northeastern Iraq, particularly in Sulaimaniyah Governorate in the Kurdistan region of Iraq, and is laterally equivalent to the Khasib, Tanuma, and Saadi formations in central and southern Iraq [5, 6].

The Kometan Formation is comprised of white-weathered, light gray, thin to thick beds of limestone, the upper parts of the formation are characterized by the existence of glauconitic and chert nodules.

Due to its economic importance and wide distribution, the formation has been described in a variety of academic publications ([e.g. 7-14]. Most of them were focused on bio- and lithostratigraphy, the origin of stylolite and chert nodules, sequence stratigraphy, and paleoenvironmental proxies of the Kometan Formation in Iraq.

In the current study, two outcrop sections around Erbil and Sulaimaniyah Governorates, northeastern Iraq (namely, Smaquli and Tabin sections) were selected for detailed petrography, microfacies, and mineralogical study using traditional petrographic and scanning electron microscopy (SEM) supported by X-ray diffraction (XRD) techniques aiming to elucidate the diagenetic processes and depositional environment of the Kometan Formation.

2. Geologic Setting

The study area is in northeastern Iraq, close to the governorates of Erbil and Sulaimaniyah. The Tabin section on the southern limb of Pirah Magrun Anticline (35°50'2.43"N; 45°06'23.97"E) and the Smaquli section on the southern limb of Safin Anticline (36°10'14.87" N; 44°35'20.46" E) are two outcrop sections that are studied (Figure 1). Tectonically, the area of study lies within the High Folded Zone of Iraq (Figure 2), which is characterized by good Cretaceous exposures (Figure 3).

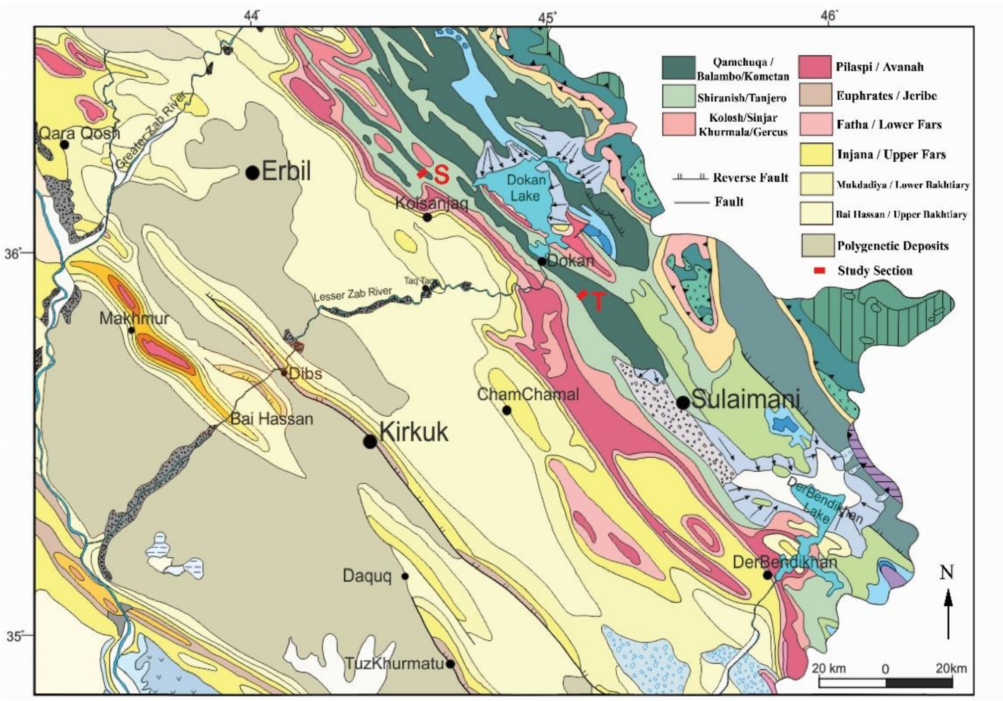

Figure 1: Geological map of northeastern Iraq and the locations of the studied sections, S; Smaquli section; and T; Tabin section. Modified from [15].

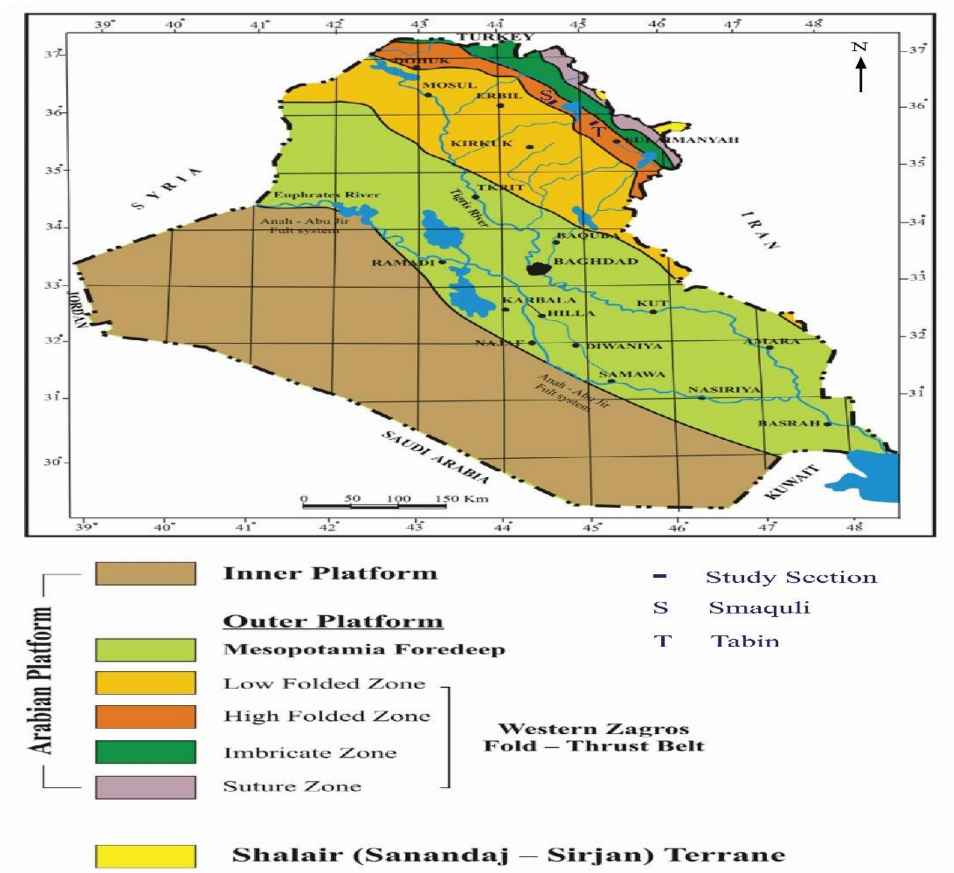

Figure 2: Tectonic divisions of Iraq [16], illustrating the location of the studied sections, S; Smaquli section and T; Tabin section.

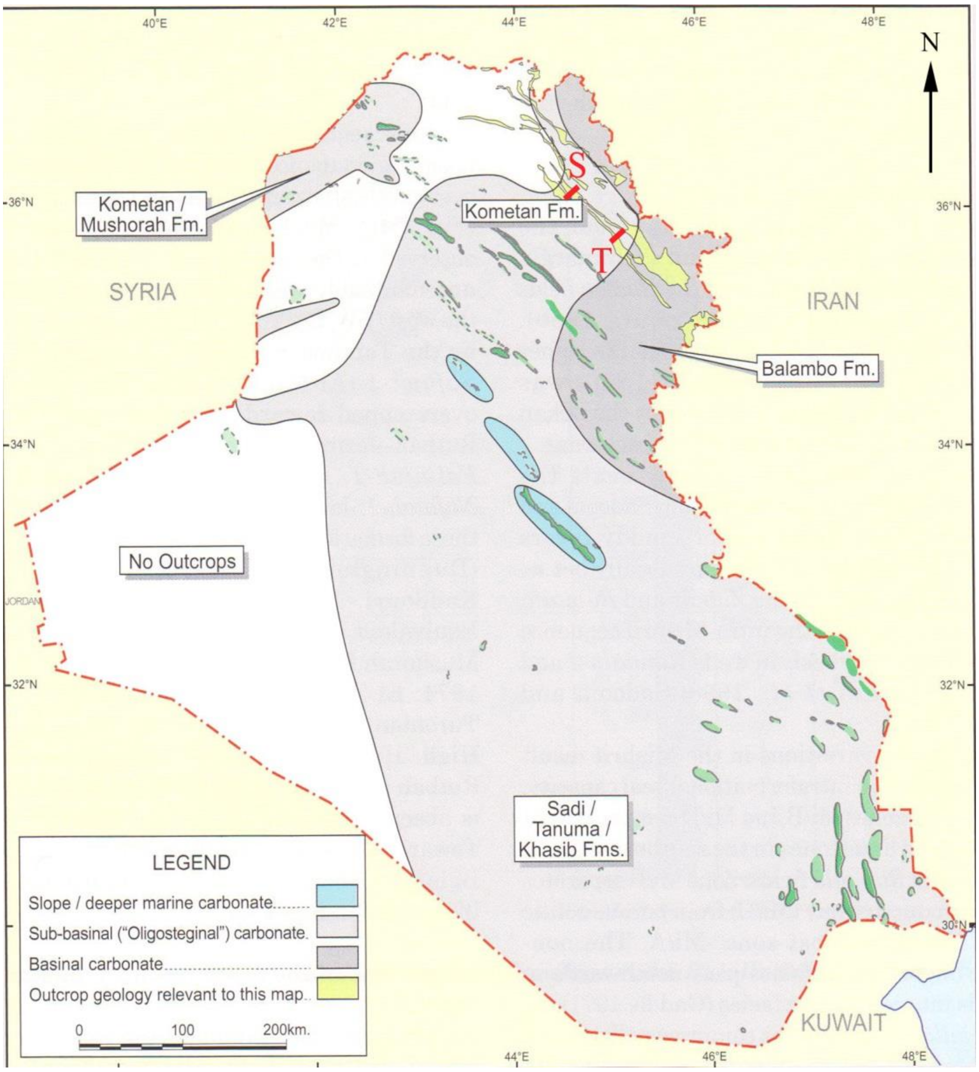

Figure 3: Paleogeography map illustrating the distribution of the Turonian- early Campanian cycle in Iraq and the location of the studied sections, S; Smaquli section and T; Tabin section (modified from [4]).

The Kometan Formation was deposited in the Cenomanian-early Campanian sedimentary main cycle [1], which was characterized by severe tectonic instability due to the effect of the Austrian and subhercynian orogenies. This main cycle is divided into two subcycles; the Cenomanian-early Turonian and the Turonian early Campanian where the Kometan was deposited in the second subcycle. During the Turonian-early Campanian, several formations were deposited, including the Kometan and Balambo in the north and the Tanuma, Saadi, and the Khasib formations in the middle and south parts of Iraq [4], (Figure 3). Additionally, Ditmar et al. [17] added the Gulneri Formation to this sub-cycle, and they also considered the Mushorah Formation as a facies within the Kometan Formation. The majority of the northeastern regions of Iraq were covered by the deep marine environment during the Turonian as a result of the rising sea level. In these areas, oligosteginal carbonate from the Kometan Formation was directly deposited over the Qamchuqa Formation (Figure 3). In some parts of northern and northwestern Iraq, the Kometan Formation was missed due to either uplifting or erosion before the deposition of Campanian sediments [18].

The stratigraphy of the studied area includes the Qamchuqa Formation (Lower Cretaceous), which is overlaid by the Kometan, Shiranish, and Tanjero formations (Upper Cretaceous). In the studied section, the Kometan Formation in Smaquli comprises 110 m of white-weathered, light grey, highly fractured hard limestone, and marly limestone, bearing nodules in the lower part (Figure 4). The Tabin section is represented by 80 m from very hard, pale grey limestone bearing nodules in the lower part and chert nodules and glauconite in the upper part of the succession. It is underlain by the Qamchuqa Formation and disconformably overlaid by the Upper Cretaceous Shiranish Formation (Figures 4 and 5).

3. Materials and Methods

The present work is based on field and laboratory examination of the Kometan Formation from northeastern Iraq. Two outcrop sections were collected from which 122 samples and thin sections were examined to assign microfacies types, diagenetic processes, and depositional models. Thin sections were half-stained with Alizarin Red-S [19] to distinguish between calcite and dolomite. Carbonate textures are carried out based on the carbonate classification models of Dunham [20]. Depositional environment concepts of standard depositional environment models and the distribution of facies were based primarily on Wilson's [21] and Flügel [22] textbooks. Fundamental diagenetic definitions were applied to recognize diagenetic features and processes.

Scanning electron microscopy (SEM) analyses were completed on selected samples at the Premier OilField Group Laboratory in Houston, U.S.A., using an FEI Quanta FEG 650 FE-SEM instrument equipped with two Bruker EDS XFlash 5030 energy dispersive X-ray spectroscopy (EDS) detectors and an FEI R580 Everhart-Thornley (ETD) electron detector. Freshly broken surfaces were created by breaking a rock segment as close to perpendicular to the bedding as possible and used for the study. Selected samples from the Smaquli section were mounted on aluminium stubs using a conductive high-viscosity glue. They were then sputter coated with 10nm of Iridium using a Leica EM ACE600 sputter coater before being placed in the SEM. The measurements were performed at a high vacuum, with an accelerating voltage of 10 kV.

X-Ray diffraction (XRD) mineralogy analysis was performed on selected samples from the Smaquli section at the Premier OilField Group Laboratory in Houston, U.S.A. on bulk rock samples using a Bruker D8 Advance XRD instrument equipped with a theta-theta goniometer with a 250 cm radius and a Lynxeye detector. All measurements were performed using CuK radiation, and the applied voltage and current were 40 kV and 30 mA, respectively. Whole rock sample preparation initially included material powdering in an agate mortar to a reasonably fine powder (<300 microns). The powdered material was further milled in a McCrone XRD mill for 13 min, which ensures a narrow grain size distribution, and brings the average grain size down to 10-20 microns. Quantification of mineral phases in the bulk diffraction pattern is accomplished using the TOPAS software package.

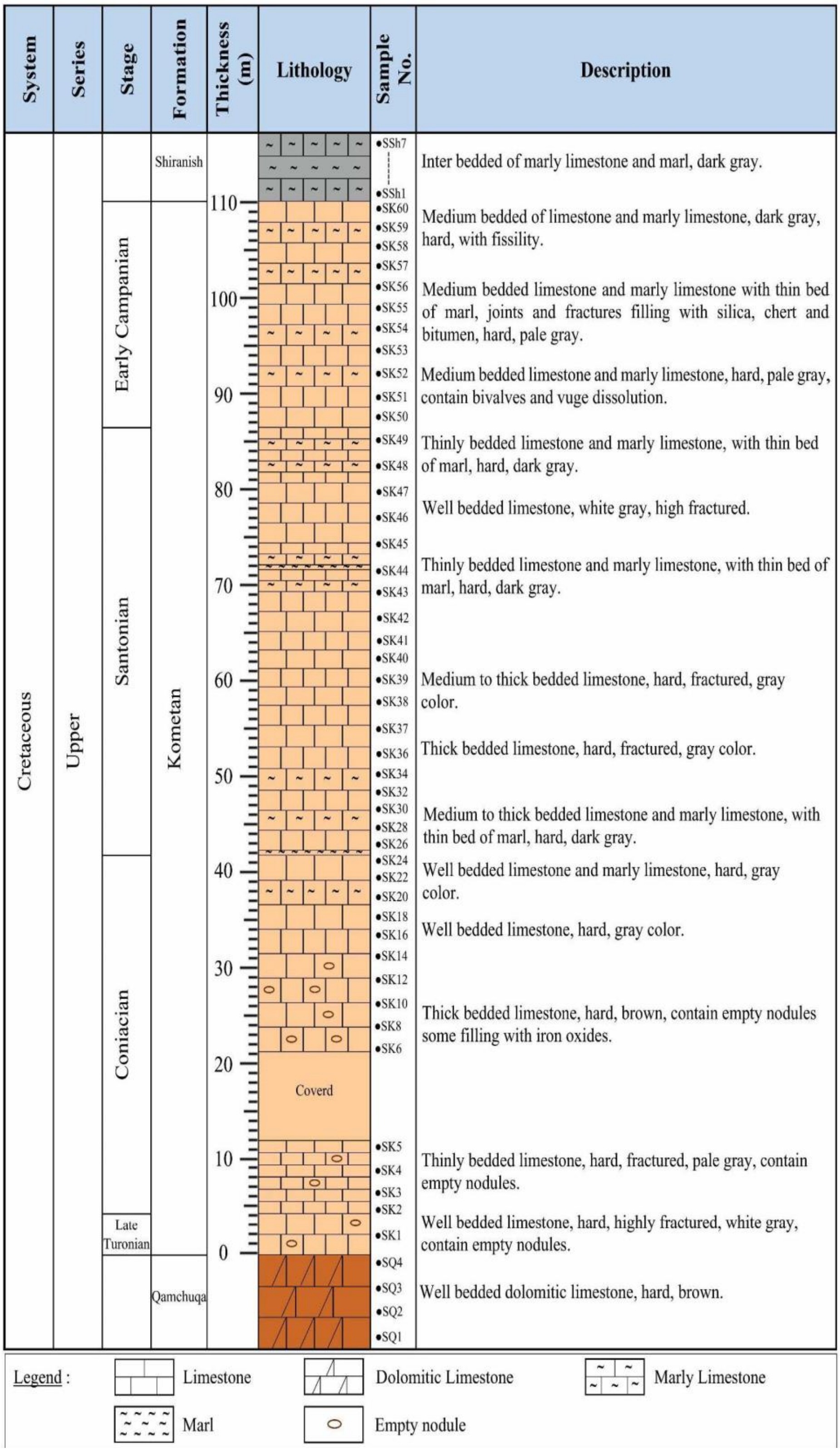

Figure 4: Lithostratigraphic column of the Kometan Formation at Smaquli Section shows the lithologic characteristics and sample locations.

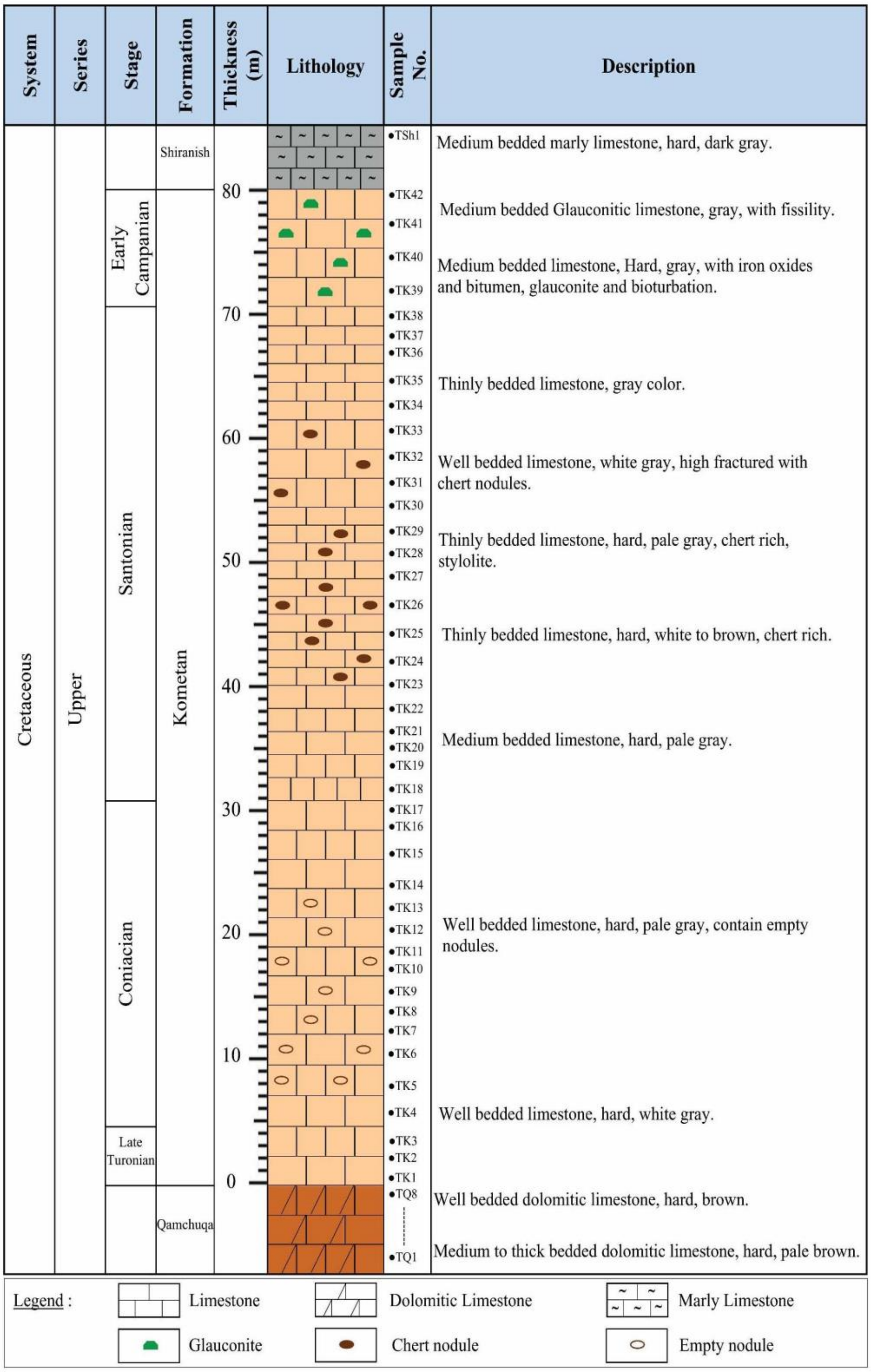

Figure 5: Lithostratigraphic column of the Kometan Formation at Tabin Section shows the lithologic characteristics and sample locations.

4. Results and Discussion

4.1. Lithostratigraphy

The Kometan Formation in the Smaquli section (Figure 4) is composed mainly of hard limestone and marly limestone, fractured and medium-bedded with white and gray colors and bearing empty nodules in its lower part (Figure 6A), with a thickness of 110 m (Figure 6B).

Massive, brown, dolomitic limestones make up the lower boundary with the Qamchuqa Formation (lower Cretaceous), whereas the upper boundary with the Shiranish Formation (Upper Cretaceous) is unconformable. In the Tabin section (Figure 5), the Kometan Formation comprises 80 m of limestone, very hard and pale grey in color (Figure 6D), with empty nodules in its lower part, common chert nodules (Figure 6E), and glauconite in the upper part of the succession. The Shiranish Formation disconformably overlies the lower boundary with the Kometan Formation (Figure 6F).

4.2 Petrographic description

4.2.1. Carbonate components (Figures 7-11).

The components of carbonate rocks can be divided into two groups: orthochems and allochems [23]. Allochems include two main categories of skeletal and non-skeletal carbonate particles [22]. The Kometan Formation is dominated by skeletal carbonate particles that are composed of planktonic foraminifera, benthic foraminifera, oligosteginal calcispheres, echinoderms, ostracods, and bioclasts. Micrite is the main type of orthochems in the studied formation. In addition, the commonly important non-carbonate components include pyrite and glauconite. Calcite is the main mineralogical component as revealed by XRD analysis in addition to traces of quartz and clay minerals represented by chlorite, kaolinite, and illite-mica (Figure 7).

Figure 6: Field photos of the Kometan Formation in the studied sections. A: Hard fractured limestone and nodules (pits), (arrows) in the lower part of the Kometan Formation, Smaquli section. B: Succession of the Kometan Formation in the Smaquli section. C: Lower contact between the Kometan and Qamchuqa formations in the Smaquli section. D: Succession of the Kometan Formation in the Tabin section. E: Chert nodules (arrows) in middle part of the Kometan Formation in the Tabin section. F: Upper contact between Kometan and Shiranish Formations in the Tabin section.

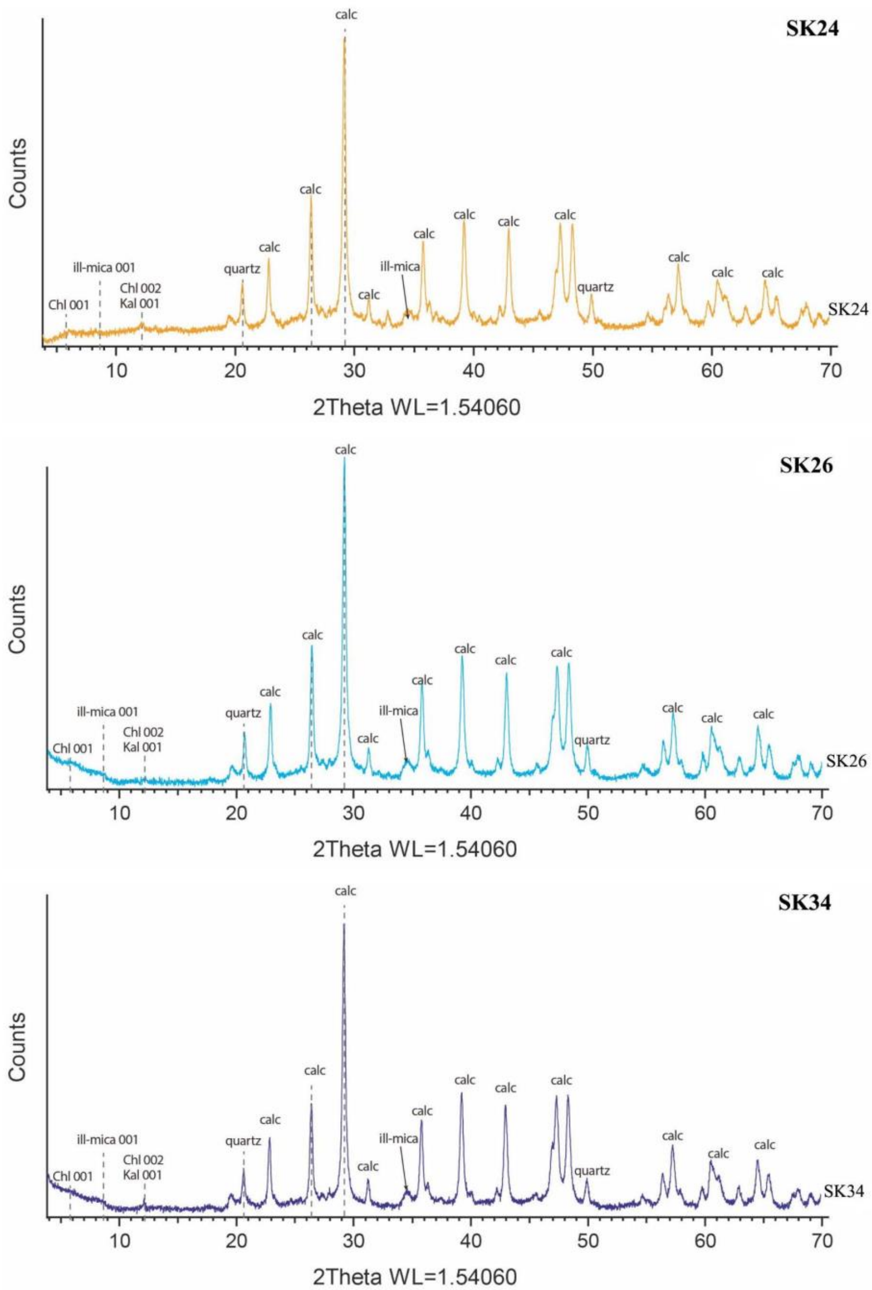

Figure 7: Selective X-ray diffractograms of some samples of the Kometan Formation in the Smaquli section (SK24, 26 and 34) see Figure (4) for samples location. Calcite is the dominant mineral in addition to other clay and non-clay mineralogical components. Chl = chlorite, ill-Mica = illite-mica, Kal = kaolinite, calc = calcite).

4.2.2. Diagenetic features (Figures 8-11)

Petrographic analysis of the Kometan Formation showed several diagenetic features in the studied thin sections which include a paragenetic sequence; chemical compaction (stylolite formation), dissolution, recrystallization, and cementation.

Compaction: Compaction is a diagenetic process that reduces the bulk volume of rocks [24]. Compaction consequences are generally recorded in sedimentary rocks in two ways: mechanical and chemical (pressure solution) [25]. Petrographic studies of the Kometan

Formation revealed the presence of the type of chemical compaction in the form of pressure–solution and stylolite formation (Figures 8E and 9B).

Dissolution: Compared to the micritic groundmass, the effect of dissolution is more apparent in the skeletal grains. Dissolution in the Kometan Formation created different types of porosity, the most common is the fabric-selective that is controlled by the components of the original rock, such as intraparticle and moldic porosity (Figure 11A). It also has a pronounced effect on calcite hexagonal grains and overgrowth (Figure 10A, D, F).
Recrystallization: It is caused by thermodynamics leading to the crystal form change of calcite or dolomite to coarser crystals [26]. This process is observed by the patchy distribution of fine-to-coarse-sized calcite crystals with intercrystalline boundaries between them (Figure 9E).

Cementation: Cementation is the chemical precipitation of calcium carbonate between or inside grains, as well as in pores and fissures [27]. Calcite cement is the most common type of cement in the Kometan Formation. This type of cement has commonly filled fossil shells and was observed in different ways, including granular, blocky, and fibrous cement (Figures 8A, B; 9A, C, D; 10E, F). In SEM images, various polymorphs of calcite have been identified; euhedral (rhombohedral) crystals, star-shaped calcite micro crystals, and a cluster of hexagonal, columnar calcite crystals (Figures 9 and 10).

4.3. Microfacies Description and Interpretation

The microfacies description revealed the presence of two main microfacies types lime wackestone microfacies which include more than 10% of grains, and mud-supported and grain-supported lime packstone microfacies which are characterized by mutual grain contacts and micritic groundmass. Based on bioclast variation, these two microfacies are subdivided into seven submicrofacies.

The submicrofacies include;
Keeled Planktonic Foraminiferal Wackestone (W1), (Figure 8 A, B)
This microfacies is distributed in the middle parts of the Kometan succession in both studied sections (Figure 12), with a thickness of 5-10 m. It is composed mainly of limestone with skeletal grains forming about 10-40% of the total facies constituents. Planktonic foraminifera of keeled type forms about 60% of the total skeletal grains, including *Dicarinella*, *Marginotruncana*, *Globotruncana*, and *Contusatruncana*, in addition to globular chamber types. Benthic foraminifera and bioclasts are also present in a few percentages. These constituents were commonly dispersed in micritic groundmass with scattered pyrite clusters.

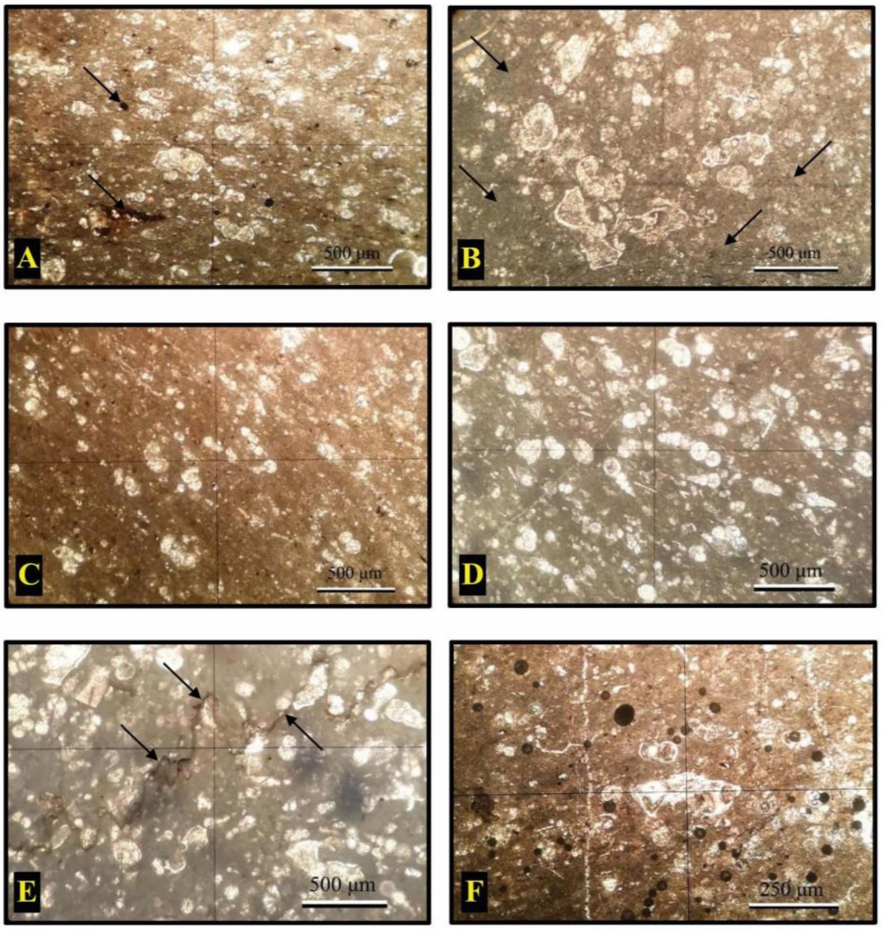

Figure 8: Microfacies of the Kometan Formation showing also some petrographic and diagenetic features (see Figures 4 and 5 for sample locations). A: Keeled Planktonic Foraminiferal Wackestone microfacies including pyrite (black arrow). Note common granular calcite cement filling foraminiferal chambers. Sample No. SK24. B: Keeled Planktonic Foraminiferal Wackestone Submicrofacies in micrite groundmass (black arrow). Note common granular calcite cement filling foraminiferal chambers, Sample No. TK16. C: Globular Chamber Planktonic Foraminiferal Wackestone Submicrofacies. Sample No. SK8. D: Globular Chamber Planktonic Foraminiferal Wackestone Submicrofacies. Sample No. TK10. E: Planktonic Foraminiferal Wackestone Submicrofacies affected by chemical compaction (Stylolite) (black arrow). Sample No. TK35. F: Planktonic Foraminiferal Wackestone Submicrofacies. Sample No. SK53.

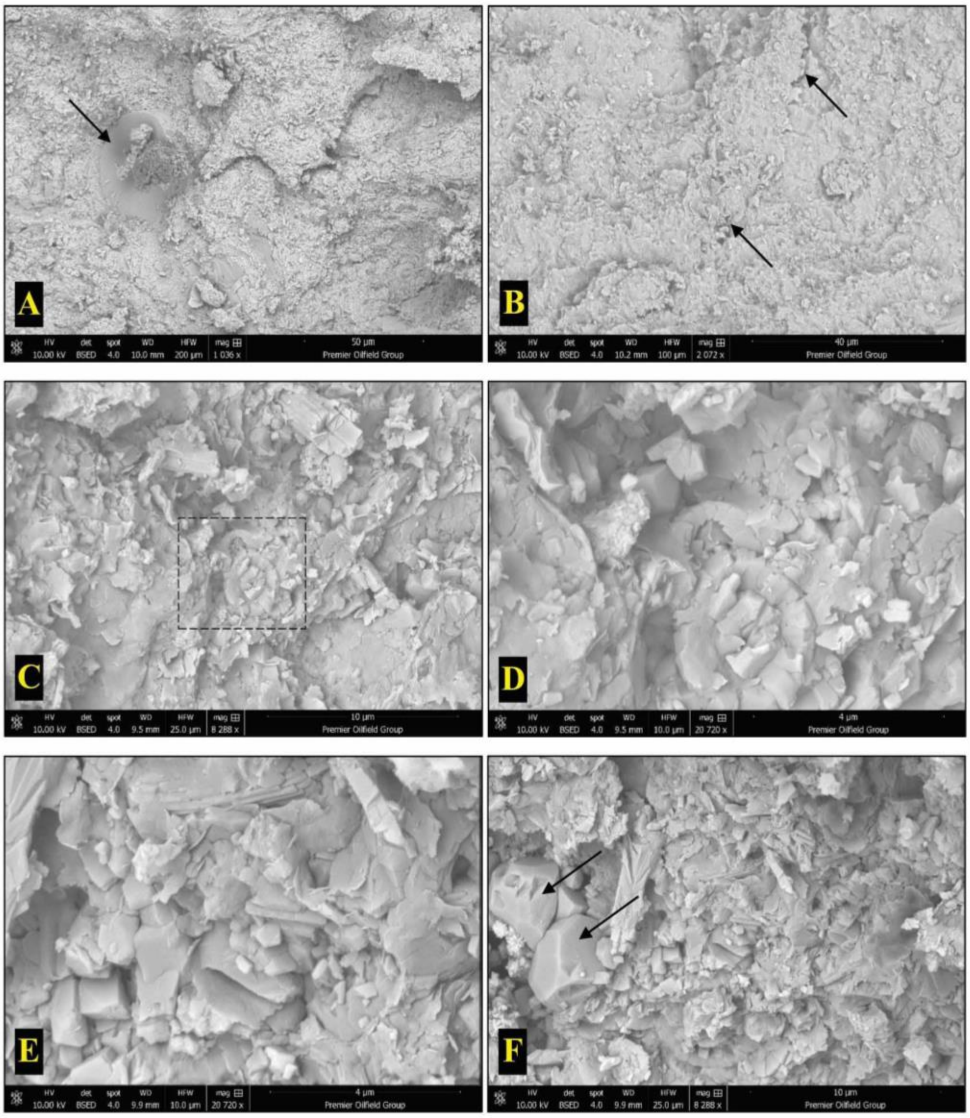

Figure 9: Scanning electron microscopic images showing some petrographic and diagenetic features (see Figure 4 for sample locations). A: Cementation within fossil shell (black arrow). Sample No. SK24. B: Chemical compaction (Stylolite) (black arrow). Sample No. SK36. C: Cementation within fossil chamber. Sample No. SK35. D: Enlarged view of C, showing cementation within fossil chamber as blocky calcite cement, Sample No. SK35. E: Recrystallization. Sample No. SK35. F: Euhedral (rhombohedral) calcite crystals with dissolution pits (black arrows). Sample No. SK35.

Interpretation:

The bioclast of the wackestone submicrofacies refers to deposition in deep marine outer shelf environments, particularly in the upper bathyal, as indicated by the high percentage of keeled planktonic foraminifera [28-30]. This microfacies could be correlated with the standard microfacies (SMF-8, [22]) that was deposited in the facies zone (FZ-2; [21]) which represents the open outer shelf setting (Figure 13).

Globular Chamber Planktonic Foraminiferal Wackestone (W2), (Figure 8 C, D)

This is one of the common microfacies in the lower parts of the Kometan Formation in the studied sections (Figure 12). It is composed mainly of 10-50 m thick limestone. Planktonic foraminifera with globular chambers form about 60% of the skeletal grains and is largely composed of species of *Whiteinella*, *Globigerinelloides*, *Archaeoglobigerina*, *Heterohelix*, and

Hedbergella followed by keeled planktonic foraminifera, benthonic foraminifera, ostracods, and a few bioclasts. These components are embedded in pale to dark brown micrite groundmass due to common organic matter content.

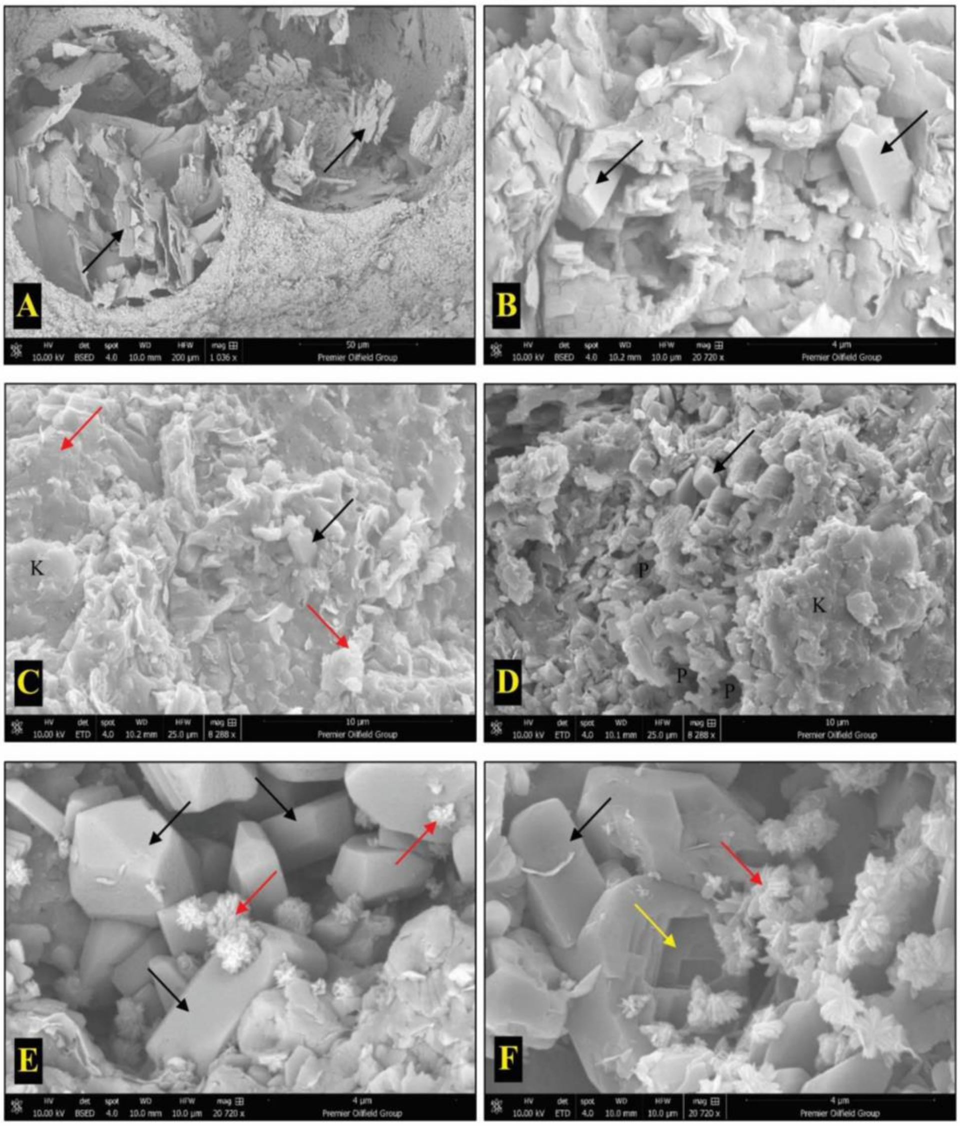

Figure 10: Scanning electron microscopic images showing some petrographic and diagenetic features (see Figure 4 for sample locations). A: Dissolution of a fossil shell, overgrowth of calcite crystals, clay minerals (Illite) (black arrow). Sample No. SK26. B: hexagonal, columnar calcite crystals (black arrows). Sample No. SK36. C: Hexagonal columnar calcite crystals (black arrow), clay minerals (fibrous Illite) (red arrow) and degraded kaolinite (k). Sample No. SK36. D: hexagonal, columnar calcite crystals (black arrow), degraded kaolinite (k), dissolution signs with pores (P). Sample No. SK36. E: Cluster of hexagonal, columnar and euhedral (rhombohedral) calcite crystals, (black arrows) and star-shaped calcite microcrystals (red arrow). Sample No. SK26. F: Hexagonal calcite crystals (black arrow) and star-shaped calcite microcrystals (red arrow), and the effects of dissolution on overgrowth calcite (yellow arrow). Sample No. SK25.

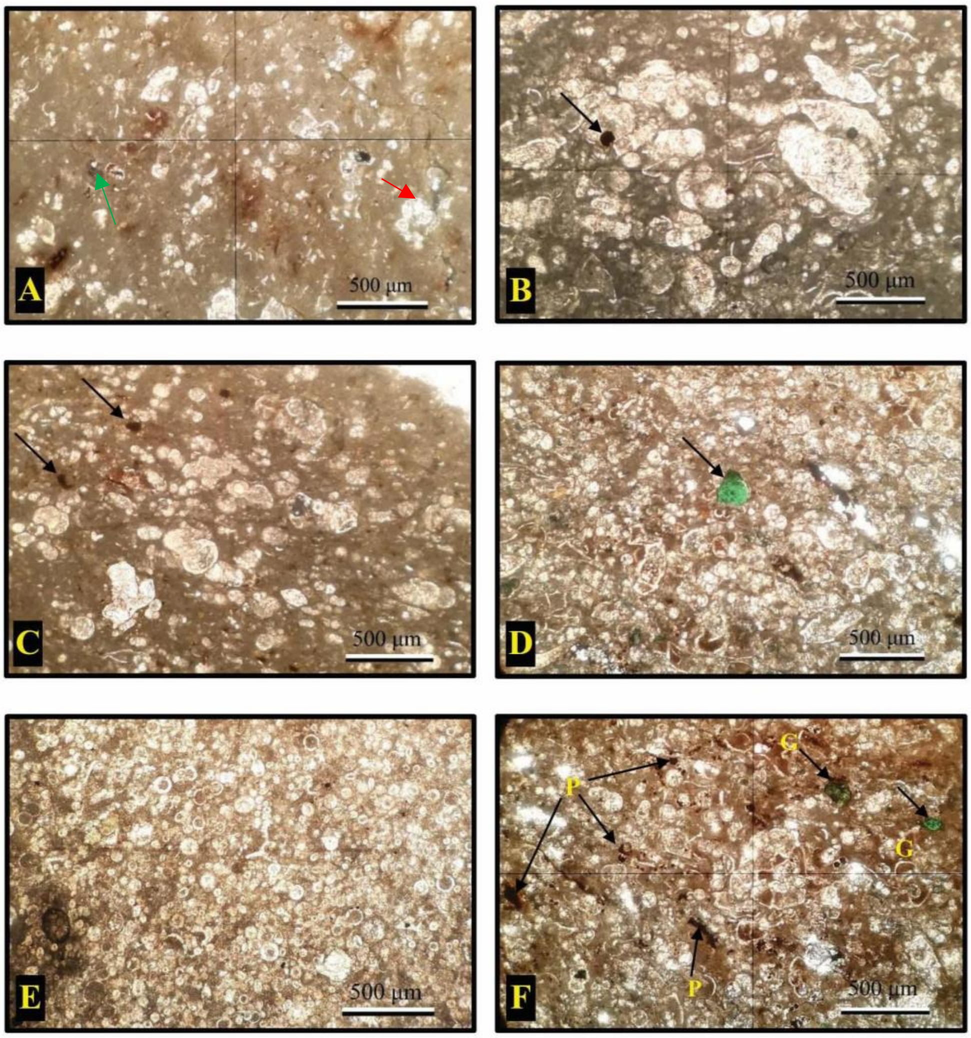

Figure 11: Microfacies of the Kometan Formation showing also some petrographic and diagenetic features (see Figures 4 and 5 for sample locations). A: Bioclastic Lime Wackestone Submicrofacies. Note the presence of interparticle (red arrow) and moldic porosity (green arrow), Sample No. TK42. B: Keeled Planktonic Foraminiferal Packstone Submicrofacies with glauconite (black arrow). Sample No. TK25. C: Keeled Planktonic Foraminiferal Packstone Submicrofacies including glauconite mineral (black arrow). Sample No. SK26. D: Planktonic Foraminiferal Lime Packstone Submicrofacies, note the presence of glauconite (black arrow). Sample No. TK39. E: Oligostegainal Lime packstone Submicrofacies. Sample No. TK5. F: Pyrite (P) and glauconite (G) minerals. Sample No. TK39.

Interpretation:

High planktonic foraminifera content in this microfacies may refers to deposition on outer shelf environments [31,32]. However, the high percentage of planktonic foraminifera of globular chambers and low content of keeled types refer to continental shelf environment with warm water conditions [28], including settings near shore, less than 100 m depth as indicated from the high content of *Heterohelix* genus [28]. The overall content of this microfacies refers to the outer shelf setting correlated to standard microfacies (SMF-3; [22]) that was deposited in the facies zone (FZ-3; [21]) represented by open marginal deep shelf (slope environment), (Figure 13).

Planktonic Foraminiferal Wackestone (W3), (Figure 8 E, F)

This microfacies is recorded in the upper parts of the Kometan Formation (Figure 12). The skeletal grains have fewer percentages than in the previous microfacies and may refer to a decrease in these skeletal components upward the formation. Planktonic foraminifera forms about 70-80% of the skeletal components and is represented by nearly equal contents of the keeled type represented by (*Dicarinella, Marginotruncana, Globotruncana, Globotruncanita*, and *Contusatruncana*) and globular chambers types (*Archaeoglobigerina, Heterohelix, Hedbergella, Whiteinella*, and *Globigerinelloides*) with good preservation of these species. Bioclasts and benthonic foraminifera are additional skeletal components. This microfacies also contains pyrite, and the groundmass was composed entirely of pale to dark brown micritic material.

Interpretation:

Faunal and sedimentological proxies show that this microfacies was deposited in the outer shelf environment [32, 33]. It could also be correlated with the standard microfacies (SMF-8; [22]) that was deposited in the facies zone (FZ-2; [21]) represented by the open sea shelf (Figure13).

Bioclastic Lime Wackestone (W4) (Figure 11A)

It is found in the upper part of the studied Kometan Formation no more than 2 meters thick (Figure 12). The skeletal grains form about 50% of the total components from which the bioclasts form more than 50%. They belong mostly to planktonic and some benthonic foraminifera and a few other bioclasts. The common planktonic species include; (*Globotruncana, Globotruncanita, Globigerinilloides, Heterohelix,* and *Hedbergella*). The groundmass is formed from pale to dark brown micrite depending on the content of organic and clay materials. It also contains pyrite and glauconite (Figure 11F).

Interpretation:

The constituents of this microfacies refer to deposition in the upper parts of the outer shelf environment [21, 34, 35, 25] and could be correlated with standard microfacies (SMF-9; [22]) that was deposited in the facies zone (FZ-2; [21]) that represented by a margin of the open sea shelf toward slope environment (Figure 13).

Keeled Planktonic Foraminiferal Packstone (P1), (Figure 11B, C)

This microfacies existed in the middle parts of the Kometan succession in the studied sections (Figure 12). The skeletal grains dominate this facies with about 80% content of the microfacies. Keeled planktonic foraminifera forms 70% of these skeletal grains and is represented by species *Dicarinella*, *Marginotruncana*, *Globotruncana* and *Contusatruncan* whereas, globular chambers types form about 20% of the skeletal grains with few contents of bioclasts. Some benthonic foraminifera, ostracods and, pyrite also are present. All components are embedded in the micritic groundmass.

Interpretation:

This microfacies reflects relative deepening in the depositional environment of the Kometan Formation. The dominance of keeled planktonic foraminifera may refer to deposition in deep marine outer shelf environments, particularly in the middle bathyal (Figure 13). It also correlates with standard microfacies (SMF-10; [22]) that was deposited in the facies zone (FZ-2; [21]) represented by the open sea shelf environment.

Planktonic Foraminiferal Lime Packstone (P2), (Figure 11D)

This microfacies appeared in the upper parts of the Kometan Formation with few thicknesses (Figure 12). The skeletal grains dominate this facies with about 80% content with common bioclasts of planktonic foraminifera. These bioclasts are characterized by their small to medium sizes and good sorting with varying forms either from keeled types *Globotruncana*, *Globotruncanita*, and *Contusatruncana* or globular chambers type *Archaeoglobigerina*, *Heterohelix*, and *Hedbergella*. This microfacies also contains about 10% of benthonic foraminifera and ostracods in addition to about 5% of undifferentiated bioclasts that are embedded in pale to dark brown micritic groundmass.

Interpretation:

This microfacies correlates with standard microfacies (SMF-2; [22]) that was deposited in the facies zone (FZ-2; [21]) and represent the open sea shelf environment (Figure 13).
Oligostegainal Lime Packstone (P3), (Figure 11E)

This microfacies is found only in the lower part of the Kometan Formation in the Tabin section only (Figure 12). It is characterized by dominating calcispheres (Oligostegina) in 60-80% of the total grains in addition to about 20% of foraminiferal species such as *Marginotruncana, Globigerinelloides, Whiteinella, Heterohelix,* and *Hedbergella* and their skeletal clasts.

Interpretation:

The composition and texture of this microfacies refer to deposition in an open marine environment with quite low energy and reduction conditions below the wave action [36-38]. It correlates with standard microfacies (SMF-2; [22]) that was deposited in the facies zone (FZ-2; [21]) and represents the open sea shelf environment (Figure 13).

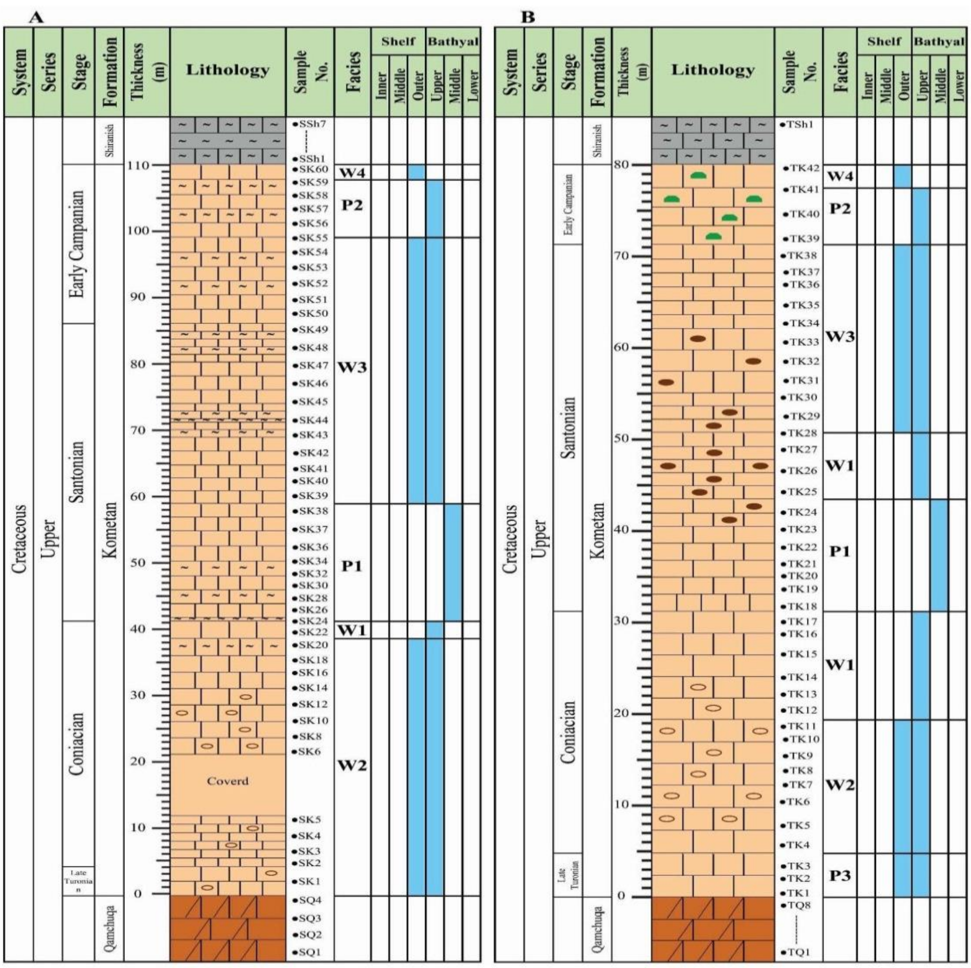

Figure 12- Microfacies distribution on both the studied sections, A, Smaquli section B,Tabin section

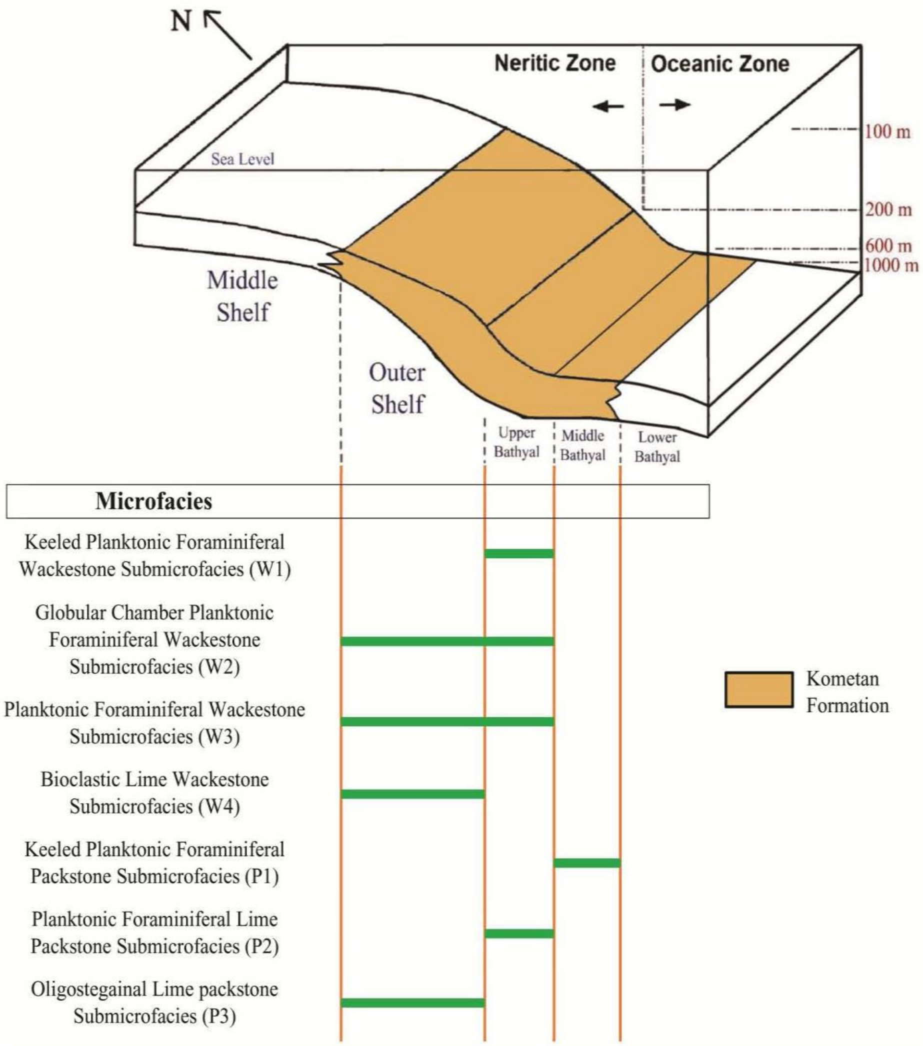

Figure 13: Suggested depositional model for the Kometan Formation in the study area and microfacies distribution.

5. Concluding Remarks

5.1. Paleoenvironmental indications

The petrographic and microfacies studies revealed that the Kometan Formation was deposited in the marine environment. This is concluded from several sedimentological and faunal indications;

5.1.1. Sedimentological indicators

1-The small sizes of the skeletal grains and the rare occurrence of larger ones, in addition to the absence of detrital quartz, all indicate the low-energy, offshore and deep environment of deposition.

2-Embedding of all microfacies components in micritic groundmass and absence of sparry calcite (orthosparite) is another indication for deposition in quiet, usually below wave base or in protected areas, (low-energy settings) that permits carbonate mud to settle [20,21].

3-Dominance of calcite as the main mineralogical composition as observed in petrographic and scanning electron microscopic images and in XRD analysis and the absence of dolomite is an indication of a deep marine environment of deposition.

4-Presence of pyrite throughout the Kometan Formation and glauconite in the upper parts of the formation may indicate that deposition occurs in a deep, quiet, oxygen-depleted environment, [39, 40]. Pyrite commonly indicates the deposition in reducing conditions in below-wave-base action within an open marine environment [38].
5- The dominance of dissolution features indicates deposition in quiet and deep environments.
6-Absence of high-energy deposition features such as oolite and coarse lithoclasts reflects the quiet and deep environment of deposition too.
7-The presence of organic matter reflects the low-energy, marine and quiet water conditions. These organic matters particularly in a reducing environment play a role to save planktonic foraminifera in sediments [41].

5.1.2 Faunal indicators

1-Dominating planktonic foraminifera (keeled and globular chamber types) and less common benthonic ones are good indications for deposition in deep marine environments. Variation in the content of globular or keeled types reflects their location and distribution on the deep marine environment.
2-The low presence of fine-grained bioclasts dominated by planktonic foraminifera debris may indicate quiet and deep setting of deposition.
3-Presence of oligostegina along with planktonic foraminifera is a good indication for quiet and deep environment of deposition.
4- The absence of fossil indexes of high-energy deposition such as large benthonic foraminifera, large bioclast, and algae is another indication for deposition in a quiet, low-energy deep environment.

5.2 Depositional Environment

Based on the microfacies divisions of [21] and [25], the studied Kometan succession is composed of alternated microfacies representing the standard microfacies SMF-2, SMF-3, SMF-8, SMF-9, and SMF-10 that were deposited in the facies zones FZ-2 (open sea shelf) and FZ-3 (deep sea margin). By comparing the characteristics of microfacies of these two facies zones with the paleoenvironmental zones of Koutsoukos and Hart [29] and Lalli and Parsons [42], the studied microfacies are similar to the outer shelf and middle-upper bathyal environments (Figure 13).

The outer shelf environment represents the deep part of the shelf that lies between 100-200 m [43] characterized by normal salinity, 10-30°C temperature, and below the effective wave base [34]. This environment is determined by the dominance of planktonic foraminifera, oligosteginal calcispheres and bioclasts in the studied samples. The common microfacies in both studied sections of the Kometan Formation which reflect the outer shelf environment are W1, W2, W3, W4, and P3 (Figure 12). Another indication for the outer shelf, marine, and low sedimentation rate deposition of the Kometan Formation is the presence of glauconite along with bioclasts and some benthonic foraminiferal species in sediments already dominated by planktonic foraminifera [34].

The presence of oligosteginal calcispheres is an indication of deposition in deep marine environments [44, 45]. Calcispheres are generally associated with carbonate sediments were deposited in low-energy deep marine platform settings [46] commonly in limestone succession of the Jurassic and Cretaceous [47]. They are common in the outer shelf and upper part of the slope where quiet, low-energy conditions below the wave base effect dominate. The dominance of calcispheres in such settings may reflect shelf margin, warm conditions, normal salinity, and enrichment with calcium carbonates conditions [35, 48]. Several studies have also mentioned that oligosteginal-rich microfacies were deposited in the basinal and outer slope environments of Tethys in the Cretaceous [49-52; 36, 37].

The deep basinal (middle-upper bathyal) environment represents the open sea shelf and the deep part of the marginal shelf with a depth of 200-1000 meters. In the current study, this environment was identified according to the presence of planktonic foraminifera, particularly the keeled type, and the mud-supported groundmass. A microscopic study shows that most of the Kometan microfacies were deposited in deep basinal environmental zones that are characterized by their fine micritic texture and high content of planktonic foraminifera (Figures 8, 11, and 13). The upper bathyal microfacies are represented by (W1, W2, W3, P2, and P3) are distributed throughout the formation in both the studied sections (Figure 13), whereas, the middle bathyal are represented by P1 microfacies that exist in the middle part of the formation. The common presence of planktonic foraminifera as compared to the benthonic type is an indication of a deep marine environment of deposition in quiet settings between the outer shelf and the continental slope [53, 54].

The dominance of keeled foraminifera (*Dicarinella, Marginotruncana, Globotruncana, Globotruncanita* and *Contusatruncana*) refers to deposition in the deeper part of the bathyal (middle bathyal) environment as compared to the globular chambers types (Whiteinella, Globigerinelloides, Archaeoglobigerina, Heterohelix, and Hedbergella) that refer to the shallower depths such as the upper bathyal [28, 55- 57].

According to Boggs [58], the overall sedimentological and biological characteristics such as common stylolite, the fine brown to dark colored micritic groundmass due to muddy and ferruginous materials, in addition to the dominance of planktonic foraminifera, and their sandy and silty-sized bioclasts, refer to deposition in marine settings within a depth of 100-1000 meters. This depth range represents the bathyal zones (middle and upper bathyal) and outer shelf that coincides with the characteristics of the studied Kometan Formation (Figure 13).

In conclusion, detailed petrographic and microfacies investigations on Kometan Formation in newly studied sections from northeastern Iraq have revealed that the formation consists of two microfacies; lime wackestone and lime packstone microfacies that were deposited in a quiet, deep environment of deposition in a marine environment. This conclusion is based on the dominance of planktonic foraminifera with a low presence of benthonic foraminifera, fine-grained bioclasts, and algae that refer to shallower and high-energy depositional conditions.

The above-mentioned biological proxies are supported by other sedimentological and petrographic indications that promote the deep, quiet, low-energy deposition of the Kometan Formation in the studied region. These include small sizes of the skeletal grains, the dominance of calcite as the main mineralogical composition and the absence of detrital quartz, the presence of pyrite throughout the Kometan Formation and glauconite in the upper parts of the formation, the embedding of all microfacies components in micritic groundmass and absence of high-energy deposition features such as oolite and coarse lithoclast

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