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Microfacies analysis of the Late Maastrichtian- Danian Phosphatic Succession in the H3-Trebeel district, Western Desert of Iraq

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Abstract

The Late Maastrichtian–Danian phosphatic succession prevails as a deposit to the west of Rutbah region, Western Iraq. This is manifested through the lithostratigraphic sections of boreholes (K.H5\6 and K.H 5\8) drilled previously in the area. The succession is mainly composed of phosphate, shale, porcelanite, oyster and foraminiferal carbonate lithofacies belonging to Digma and Akashat formations. Three facies association**s** are distinguished during the study: the phosclast planktonic (FA1) that dominates the outer ramp, the phosclast foraminiferal (FA2) that dominates the mid ramp, and the quartz dolomitic phosclast (FA3) present in the inner ramp. These facies' associations are differentiated into seventeen microfacies types. Microfacies analysis and fauna contents have shown gradual facies variation grading from a high energy inner ramp environment in the east to a low energy deep water ramp environment in the west.

Keywords: Paleocene; Maastrichtian; Danian; Foraminifera; Digma Formation; Akashat Formation; Western Iraq.

تحليل السحنات الدقيقة للتتابع الطباقي الفوسفاتي الماسترختي الاعلى – دانيان في طريبيل – H3 الصحراء الغربية, العراق

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الخلاصة

تم دراسة التتابع الفوسفاتي الصخاري لعمر الماسترختيان– الدانيان غرب مدينة الرطبة, غرب العراق عبر لباب البئرين (K.H5\6 و K.H 5\8) المحفورين سابقا في المنطقه وتبين ان هذا التتابع يتكون من سحنات الفوسفرايت و الشيل و البورسيلينايت و الحجر الجيري الغني بالفورامنيفرا واصداف النواعم والتي تعود الى تكويني الدكمة و عكاشات . تم تمييز ثلاث سحنات مصاحبة رئيسية وهي: سحنات الفتات الفوسفاتي – الطافيات السائدة في المنحدر الخارجي(FA1), سحنات الفتات الفوسفاتي– الفورامنيفرا السائدة في المنحدر الوسطي(FA2), وسحنات كوارتز– الفتات الفوسفاتي الدولوماتي المتمركزه في المنحدر الداخلي(FA3). تم تشخيص سبعة عشر نوع من السحنات الدقيقة بانيه للسحنات المصاحبه الموصوفه. ومن خلال دراسة

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السحنات و المحتوى الحياتي نستنتج بأن السحنات تتدرج من بيئات ذات طاقة عالية للمياه الضحلة في المنحدر الداخلي شرقا الى بيئات ذات مياه عميقة هادئة للمنحدر غربا.

1. Introduction

The Cretaceous/Palaeogene (K\Pg) boundary is exposed along the south-western rim of the Ga'ara depression and extends southward to the H3 area. The K\Pg boundary is also recognized in subsurface sections from H3 to Trebeel area at the Iraq – Jordan borders. In the north-eastern rim of the Ga'ara depression, the K\Pg boundary is missing due to a major unconformity that caused the non-deposition of the Danian succession, as a result the overlying of the late Maastrichtian by Selandanian phosphorite-rich succession [1, 2]. In the western flank of the Rutbah uplift of the Iraqi western desert, the Maastrichtian-Danian phosphatic succession is widely exposed in outcrops and is also present within subsurface lithologies (Figure-1). The Late Cretaceous- Eocene phosphatic formations deposited in Iraq represent the Eastern boundary of the South Tethyan Phosphorite Province, which is highly rich in huge phosphorite deposit, especially in the Selandanian Akashat deposit [2]. The late Maastrichtian sediment had uncomformably overlain the Late Campanian- Maastrichtian, represented by Hartha and Tayarat formations [1and 3]. The Late Maastrichtian-Danian succession in the western desert of Iraq is exemplified by Digma and Akashat Formations. Akashat Formation is regarded as a source of phosphorite [3]. The Digma Formation, as described in Anah-1 well, Western Iraq, was first defined as an independent stratigraphic unit [4]. It comprises 50 m of phosphatic, glauconitic, locally silicified, and marly sediments. The succession of this formation was recognized and mapped by [5]. But, the sequence was claimed by [6] as the Digma Formation comprising the sequence of Hartha Formation with the lower part of the Tayarat Formation. Sattran and Mansour [6] were the first authors who mentioned the presence of the Digma Formation in the western desert. Hassan [7] identified the Digma Formation (Maastrichtian) in the Western Desert, and then later it was adopted by Regional and Detailed Geological Surveys (GEOSURV). The name Jeed was introduced by [3] to describe the phosphatic development of Tayarat Formation. Jeed Formation included the sequence attributed to Digma Formation and part of the Tayarat Formation. Then, the name “Jeed Formation” was revised to Digma Formation as a replacement. Mohammed [1] concluded that the Jeed Formation consist of a variety of lithofacies, such as carbonate, phosporite, shale, marl-sandstone, and porcelanite facies, which were deposited in different environments; tidal in the east and southwest while deep marine realm in the west.The age of the Digma Formation was assigned as Upper Cretaceous (Upper Maastrichtian) [1, 3, 4, 5, 7, 8, 9, 10, 11], whereas the depositional environment is regarded as deep marine environment [1, 9].

The Digma Formation conformably overlies Tayarat Formation and the upper contact is also conformable with the overlying Akashat Formation [3, 7, 8, 9, 10, 11, 12]. In addition, it unconformably overlies Tayarat Formation [1], as confirmed by the present study. The Early Paleocene succession in the Western desert of Iraq is represented by Akashat and Umm Er Radhuma formations. The phosphatic facies of Umm Er Radhuma Formation were considered as Akashat Formation [3], which was officially edited by [13]. The phosphorite Akashat Formation (Middle - Upper Paleocene) is partly restricted in occurrence to the North, west, and south flanks of the Hauran anticlinorium. Akashat Formation (Paleocene) was divided into three mapable members: Traifawi Member (Early Paleocene), Hirri Member (Middle Paleocene), and Dwaima Member (Late Paleocene) [2]. The Paleocene succession is represented by Umm Er Radhuma and Akashat Formations, deposited in the steepened ramp in the western desert [1, 14]. The main objective of this study is to classify the microfacies and detect the depositional environment of the Late Maastrichtian-Danian succession, which appeared in the subsurface sections of K.H 5\6 and K.H 5\8, based on the microfossil assemblages, skeletal grain, non- skeletal grain, intergrainular matrix, and texture type.

2. Stratigraphy and geological setting

Tectonically, the Iraqi Western Desert belongs to the stable shelf; however, the thickness and setting of strata are affected by structural and tectonic movements [15]. The Rutbah - Jezira Area is an inverted Palaeozoic basin; The Jezira region has been the portion of the Rutbah Uplift during the Late Permian to Early Cretaceous periods. During the Cretaceous period, the Jezira region subsided while the Rutbah region remained elevated. Accordingly, these two regions are classified as separate subzones [11]. The Rutbah Uplift has influenced the setting of the exposed rocks, usually causing lateral facies variations due to the changes in the depositional environment [15]. Jassim and Goff [11] reported that, during the Late Campanian and Maastrichtian periods, the climax of obduction and closure of the Southern Neo-Tethys has led to a significant transgression across Iraq as a whole. Due to deformation that occurred along the NE Tethyan margin, the Cenomanian Sea transgressed onto the Rutbah uplift which led to the reactivation of longitudinal ridges and transversal blocks. NW-SE trending ridges divided the main basin into smaller sub- basins, causing facial variations. The tectonic activity at the margins of the Arabian Plate and the narrowing of the Tethys Sea led to the development of phosphorites within the Late Cretaceous formations [15]. The supplementary type section of Latest Maastrichtian Digma Formation is suggested by [2] at Um Er Radhuma Al-Safra, about 10 Km southeast of Akashat mine, while the original type locality is in the Anah oil well 1 [4]. This Formation is exposed at Marbat Al-Hasan hill and continues westwards, along the northern rim of Ga`ara Depression, then it extends along the western rim of Ga`ara Depression, farther southwards crossing the Highway No.1, to the Iraqi – Saudi Arabian borders. The Digma Formation is underlain conformably by the Tayarat Formation [2, 7] and overlain conformably by Akashat Formation in the western and northern rims of Ga`ara Depression [6]. The type locality of the Akashat Formation is located in wadi Samhat, along the western rim of Ga'ara Depression, which is located 7 Km south of Akashat phosphate mines [2]. The Akashat Formation is exposed, only in the western and middle parts of the Iraqi Western Desert. In the subsurface, the Akashat Formation almost has a uniform extension, where it extends north and westwards. Towards north, it passes to Aaliji Formation, whereas towards east and northeast, it is replaced by Umm Er Radhuma Formation, to the east and northeast of Rutbah Uplift [15].

3. Materials and Methods

The subsurface Upper Cretaceous –Paleocene stratigraphic succession at the Western part of Rutbah province, Western desert, is studied using core samples obtained from two boreholes drilled previously in the area. The K.H5\6 borehole is bounded by (38° 56' 13"E, 32° 42' 15"N) coordinate and the K.H5\8 borehole is bounded by (39° 29' 52"E, 33° 11' 11"N) coordinate (Figure-1). 184 samples were collected within a space interval that ranged between 0.5 and 1.0 m, depending on lithological variations. Samples were used to study petrography and microfacies of the succession. The distinction between calcite and dolomite minerals was accomplished by using alizarine staining method to thin sections. The staining affects calcite, where it changes the original colour to red or purple while, on the contrary, dolomite is not affected. Thin sections were investigated by applying Denham classification of carbonate rocks [16, 17] to determine microfacies characteristics.

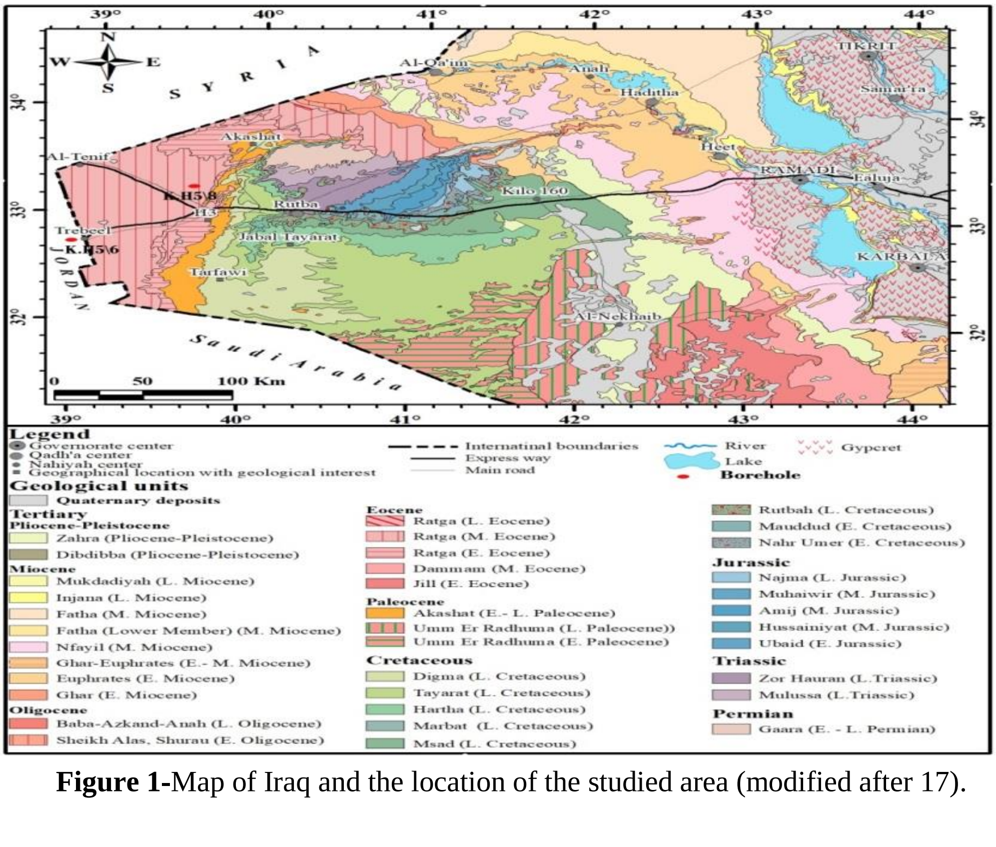

Figure 1-Map of Iraq and the location of the studied area (modified after 17).

4. Lithostratigraphy

4.1 Lithostratigraphy of K.H 5\6 section

The studied section consists of three formations: Upper part of Tayarat Formation which represents the Early Maastrichtion age, Digma Formation which represents the middle Late to late Late Maastrichtion age, and Akashate Formation which refers to the Danian age [1, 2, 9, and 14]. The latter formation is subdivided into three members: Traifawi, Hiri, and Dwaima [2]. In the borehole K.H 5\6, only the 13 m sections were described from the upper part of Tayarat Formation, which consists of dolostone. Digma Formation in K.H 5\6 comprises 64 m thick sections of limestone and marly limestone, interbedded with shale and dolomitic shale overlying the dolomitic units of Tayarat Formation and underlying the Akashat Formation. This Formation attains a thick succession of limestone characterized by moderately fine to medium-sized euhedral floating rhombic dolomite scattered in shale beds. In the studied section, the Formation can be divided into 3 lithological units from the base to the top, as described below (Figure-2).

1- The lower unit consists of fossliferous limestone, with depth interval of 197-184 m (thickness 13 m), which is characterized by the presence of planktonic foraminifera and phosphate clast.

2- The second unit consists of shale with micro rhombic dolomite filled with organic materials. It is located at a depth interval of 183-172 m. Rare planktonic foraminifera exist; it was difficult to identify them, due to the dolomitization processes that altered the rocks.

3- The upper unit consists of marly limestone interbedded with shale that is rich in planktonic foraminifera, few benthic foraminifera, and bioclast, along with few phosphate clasts. The upper part of this interval (171-133 m) is characterized by the presence of organic material in shale.

In the K.H5\6, only the lower member was studied. In the studied section, the Trifawi Member was introduced to describe a 34 m section, which can be divided into 3 lithological units from the base to the top, as described below.

1- The first 10 m consist of the basal laminated grey to black shale directly overlying the Digma Formation, with a depth interval of 133-123 m. It is characterized by the existence of a moderate percentage of planktonic foraminifera and few benthic foraminifera. This interval is characterized by the presence of organic material in shale, and it is assigned to the earlist Danian age.

2- The second unit consists of 5 m of limestone with few dolomitic rhombic crystalls, with a depth interval of 123-118 m, which is characterized by the existence of a moderate to high percentage of planktonic foraminifera and few benthic foraminifera, along with few phosphate clasts. It is assigned to the early Danian age.

3- The upper unit of the Trifawi Member consists of 6 m of dolomitic limestone, from a depth interval of 118 to 112 m, overlaid by 12 m of limestone which is rich in planktonic foraminifera, few benthic foraminifera, and few bioclasts that occur within an interval of 112 to 99 m.

4.2 Lithostratigraphy of the K.H 5\8 section

The studied section consists of three formations: the Upper part of Tayarat, Digma, and Akashate. Digma Formation in K.H 5\8 comprises 51 m thick limestone overlying the dolomitic units of Tayarat Formation, which consists of dolomitic limestone at a depth interval of 190-160 m. This unit is characterized by dolomite with medium to coarse subangles, with bad sorted quartz. The depth interval is 170-164 m, characterized by silicified limestone, whereas the interval of 164-160 m is marked by crystalline limestone. The Digma Formation underlies the Akashat Formation. Digma Formation is formed of a thick succession of limestone. In the studied section, the formation can be subdivided into 3 lithological units from the base to the top, as follows (Figure-3).

1- The lower unit consists of limestone at a depth interval of 156-160 m, which is characterized by abundant phosphate clasts and bone fragments, with rare existence of planktonic foraminifera in the upper part of this unit.

2-The second unit consists of limestone at a depth interval of 156-143 m, which is characterized by the existence of few bone fragments that are scattered in micritic groundmass. These bone fragment have large size and elongated shape, making a floatstone texture.

3- The upper unit consists of limestone at a depth interval of 156-110 m, which is characterized by the existence of planktonic foraminifera, few benthic foraminifera, and bioclast. The upper part of this unit is characterized by the presence of phosphate clasts and bone fragments, in addition to planktonic foraminifera.

The Akashat Formation belongs to the Paleocene age and is subdivided into three members based on fossils content, as follows.

Trifawi Member: The term Trifawi Shale Member was introduced to describe 7 m, of which 3 m are characterized by index planktonic foraminifera, which is overlaid by 5m of crystalline limestone. The basal laminated black shales is overlying the Digma Formation. It consists of a grey to black shale. It is assigned to the early Paleocene age (Danian). This member is characterized by the existence of index fossils of *Guemblitria cretacea* related to the Danian age Cushman, which in turn is overlaid by the Hiri Member of the same formation, which is characterized by thick units rich in shell fragments of mollusca.

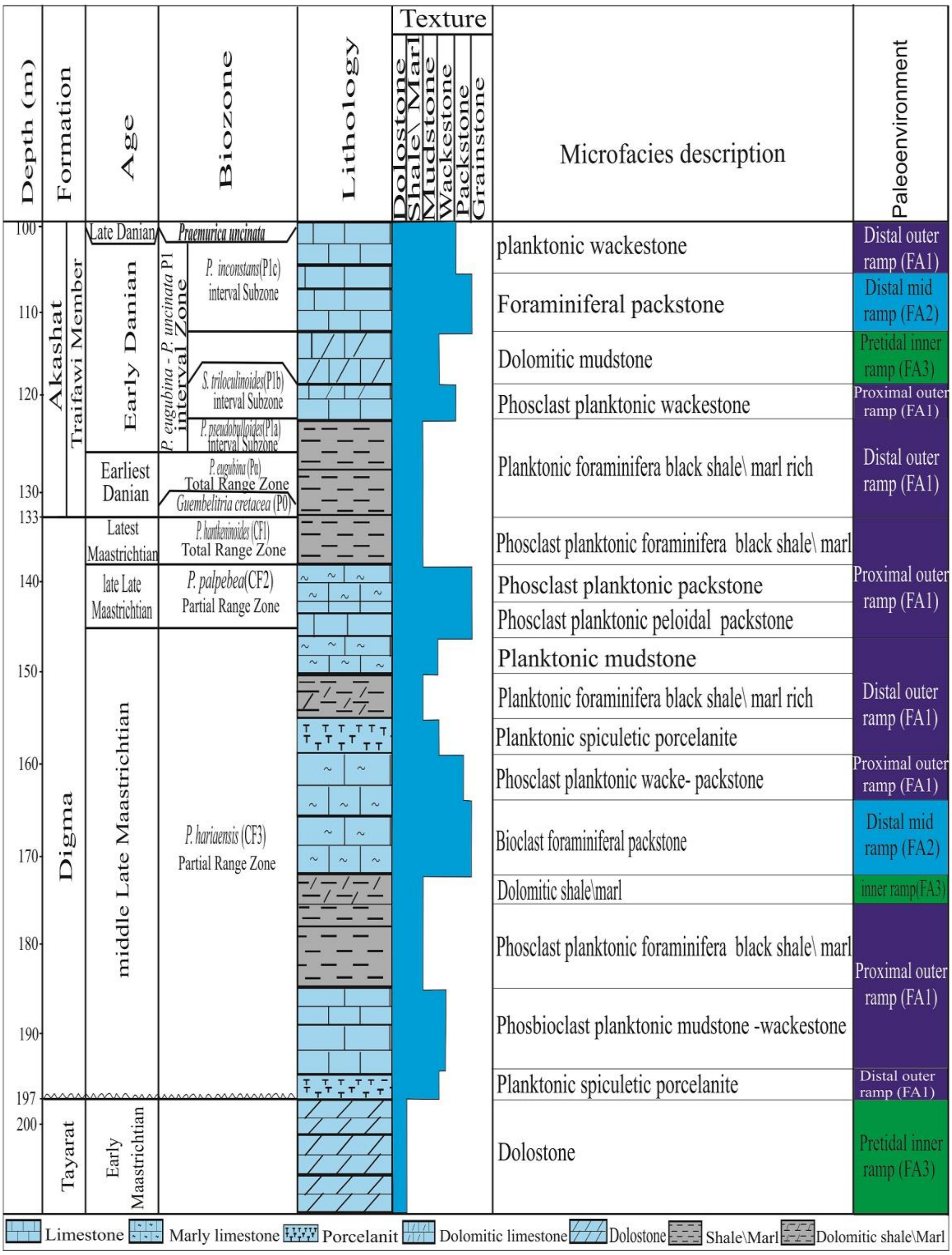

Figure 2-Lithostratigraphy, Microfacies description, and Paleoenvironment of Tayarat, Digma, and Akashat formations in the K.H 5\6 section.

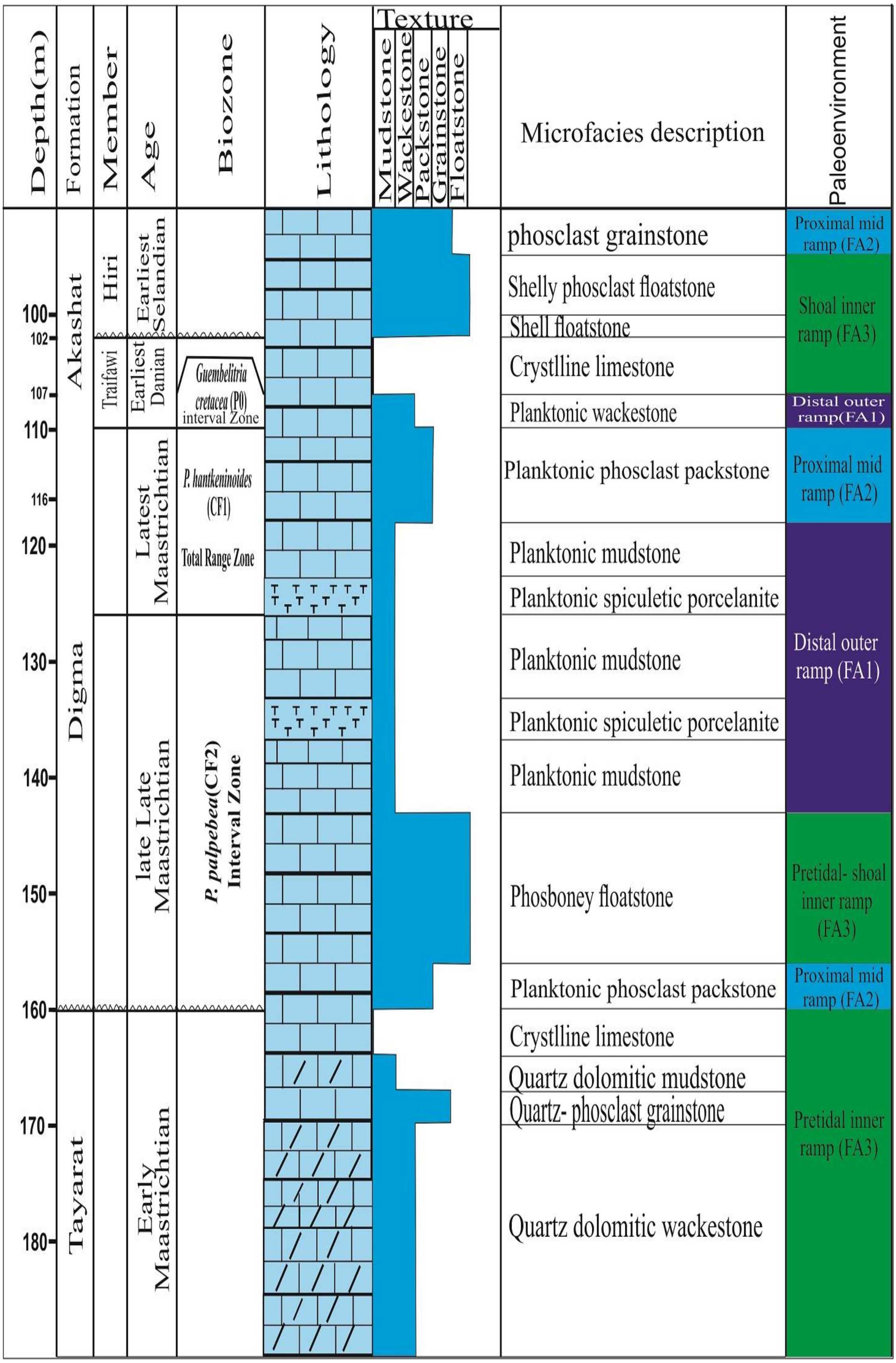

Figure 3- Lithostratigraphy, Microfacies description, and Paleoenvironments of Tayarat, Digma, and Akashat formations in the K.H 5\8 section.

5. Carbonate and non- carbonate consistency

Carbonate grains can be divided into non-skeletal and skeletal grains.

The main skeletal grains are composed of planktonic foraminifera and few benthonic foraminiferas in addition to bioclasts of echinoderm and fossil fragments that appear in small amounts in some intervals within the Digma and Akashat formations in K.H 5\6 and K.H 5\8 wells (boreholes). Shell fragments are represented by mollusk shells, such as pelecypods and gastropods, which are recognized in some intervals. The non- skeletal grains in this study are represented by peloids**,** which were found within Digma Formation in KH 5\6 in some intervals. The non- carbonate component is expressed by phosclasts and bone fragments, which represents dominant components within the Digma and Akashat formations in the borehole K.H 5\8. It also occurs in the borehole K.H 5\6 section. Phosclast is defined as a phosmud (pristine) that has been subjected to fragmentations, winnowing, reworking, and redeposition as phosphate grains. Another source for lithoclast is coprolite fragments. These terms followed the suggestions of earlier studies [1, 18]. Silica bioclast that contains mainly sponge spicules within siliceous facies was recorded in boreholes K.H 5\6 and K.H 5\8. Quartz was observed in the lower part of early Late Masstrichtion succession in the K.H 5\8 section.

6. Facies associations

Microfacies identification, classification, and analyses based on sedimentological, petrographical, and paleontological criteria are directed to predict the sedimentary system of the studied area. Mixed different rock and allochems types have been together subjected to phosphatization. The Late Maastrichtian- Danian phosphatic mixed lithofacies are composed of genetically related microfacies (MF), which interfere with each other to re-build three main association facies (FA) represented by five textural types: mudstone, wackestone, packstone, grainstone, and floatstone (Figures- 2 & 3). This gives a detailed picture of their facies distribution and depositional environment that is ranging from basinal-distal outer ramp to proximal inner ramp. There microfacies and facies association are distinguished, as described below.

6.1. Phosclast planktonic- dominated outer ramp- basinal facies association (FA1): This facies association is the most dominant, located in the middle and upper parts of the late Maastrichtian and lower part of Danian, especially around the K\Pg boundary in the K.H5\6 (Figure- 2). The FA1 is represented by different microfacies, mudstone, wackestone, packstone, shale or marl, and porcelanite. The outer ramp- basinal facies associations are exemplified in seven microfacies: MF1, MF2, MF3, MF4, MF5, MF6, and MF7, as outlined below.

6.1.1 Planktonic mudstone\ wackestone (MF1): This microfacies is recorded in a brownish- grey mudstone to wackestone. It consists of few percentages of planktonic foraminifera represented by *Globotruncana* sp., *Hedbergella* sp., *Heterohelix* sp., *Pseudoguembelina* sp. (Pl.1A), and *Rugoglobigerina* sp. They float in a micrite groundmass, with muddy to wacky texture in Digma Formation. The planktonic foraminifera of Akashat Formation are represented by *Globanomalina compressa* (Pl.3A), *Praemurica inconstans*, *Chiloguembelina midwayensi* (Pl.3B), *Chiloguembelina morsei*, *Eoglobigerina simplicissma* (Pl.3C), and *Woodringina hornerstownensis.*

Occurrences: Planktonic mudstone microfacies was introduced to describe four mm thickness, recognized in the upper part of the middle Late Maastrichtian within K.H5\6 in marly limestone (Pl.1A). This microfacies is also regarded as the main microfacies characterizing the Digma Formation in K.H 5\8, with a thickness of 17 m. Planktonic wackestone microfacies were recorded in the upper part of Akashat Formation in K.H 5\6, represented in five m. The planktonic wackestone was recorded in three m within the lower part of Akashat Formation in K.H5\8. This microfacies corresponds to RMF5 [19]. Ramp Microfacies Types (RMF) correspond in their criteria to Standard Microfacies Types of Wilson for carbonate platforms SMF [19]. The planktonic assemblages with a micrite matrix indicate a deeper subtidal distal-outer ramp to basinal facies below the storm wave base (SWB).

6.1.2 Planktonic foraminifera black shale\marl (MF2): This microfacies occurs in the shale\marl, which is rich in organic materials and contains few floating rhombic dolomites (Pl.1B), consisting mainly of moderate percentages of planktonic foraminifera represented by *Pseudoguembelina hariaensis*, *Globotruncana* sp. (Pl.3D), *Rugoglobigerina* sp., *Globotruncanella* sp., *Hedbergella* sp., and *Heterohelix* sp. These microfacies were recorded within the lower part of Akashat Formation in K.H5\6 and characterized by moderate percentages of planktonic foraminifera represented by *Guemblitria cretacea* (Pl.3F) and *Parvularugoglobigerina eugubina* (Pl.3G).

The warm water provinces are characterized by species with thick-walls and ornamented by keels. These taxa include *Marginotruncana*, *Globotruncuna*, *Globotruncanita*, and *Gansserina*, that occupy the Tethyan province [20]. The same species are recognized in these microfacies within K.H 5\6.

Occurrences: This microfacies was introduced to describe five m thickness recognized in the upper part of the Middle late Maastrichtian within Digma Formation in K.H5\6. These microfacies are recorded in ten m within the lower part of Akashat Formation in K.H5\6. This microfacies may correspond to the Biozone VII in Syria [21] and may be equivalent to RMF 5 [19]. Black shale\marl rich in planktonic foraminifera indicates the deposition in a deeper subtidal distal-outer ramp to the basinal environment.

6.1.3 Planktonic speculetic porcelanite (MF3): This microfacies consists of planktonic foraminifera such as *Pseudoguembelina hariaensis*, *Globotruncana* sp., *Rugoglobigerina* sp., *Heterohelix* sp., *Archaeoglobigerina carteri* (Pl.3H), and sponge spicules. Planktonic Foraminifera in these microfacies are represented by small-size species associated with fine sponge spicules.

Occurrences: This microfacies is observed in two intervals, the first is in the lower part of Digma Formation represented by three m, while the second is introduced to describe four m thickness recognized in the upper part of the Middle late Maastrichtian within Digma Formation in K.H5\6, along with six m thickness in K.H5\8. This microfacies corresponds to RMF 5 [19]. Mohammed (1993), depending on XRD, SEM, and chemical analysis, proved that some beds of planktonic mudstones are porcelanitic [1]. Planktonic spiculetic porcelanite indicates the deposition in the deeper subtidal distal-outer ramp to the basinal environment.

6.1.4 Phosbioclast planktonic mudstone\wackstone (MF4): This microfacies occurs in grey mudstone\ wackstone and consists of planktonic foraminifera such as *Pseudoguembelina hariaensis* (Pl.3I), *Globotruncana* sp., *Rugoglobigerina* sp., *Heterohelix* sp., and *Archaeoglobigerina carteri*, in addition to few to moderate percentages of phosbioclast, which occur as an accumulation of skeletal fragments that have been subjected to phosphatization. Planktonic Foraminifera in the lower part of Digma Formation are represented by small-sized biserial and low trochospiral spired planktonic foraminifera. Heterohelicids show high abundance in several marine environments, suggesting the ability to adapt to a wide range of water column conditions [22].

Occurrences: This microfacies is observed in the lower part of Digma Formation in K.H5\6 and is present in nine m thickness of the succession. This microfacies corresponds to RMF 5 [19]. Phosbioclast planktonic mudstone\wackstone indicates deposition in the proximal outer ramp of paleoenvironment.

6.1.5 Phosclast planktonic wackestone\ packstone (MF5): This microfacies consists mainly of planktonic foraminifera and few to moderate percentages of phosclast which has small size.

Occurrences: Phosclast planktonic wackestone that are recorded in the middle part of Akashat Formation in K.H5\6 occur in four m thickness (Pl. 1D). Phosclast planktonic wack- packstone that are recorded in Digma Formation occur in five m within the middle part. Phosclast planktonic packstone are recognized through four m in the upper part of Digma Formation in K.H5\6 (Pl. 1E). This microfacies may correspond to Biozone II in Syria [21]. This microfacies may also correspond to RMF 5 [19]. It suggests deposition in the proximal outer ramp paleoenvironment.

6.1.6 Phosclast planktonic foraminifera black shale\marl (MF6): It is characterised by the presence of high organic material of shale\marl with high proportions of planktonic species (up to 90%) and less than 10% of phosoclast (Pl. 1F). All the individuals of planktonic foraminifera include keeled species which are assigned to the deep-water form group [19] that increases in abundance towards the upper part of the Digma Formation, indicating the presence of a deep deposition basin during that time. Deepening of the basin, it is associated with the appearance of planktonic forms, such as *Plummerita hantkeninoides* (Pl.3E), *Globotruncana*, and *Globotruncanita*. These genera dwell among moderate to deep water zones and geographical environments, associated with the tropical- subtropical Tethyan realm, during Cretaceous [23]. This complex assemblage of species happened as the result of an increase in water depth that took place during the middle-late Late Maastrichtian.

Occurrences: This microfacies is represented by fifteen m thickness, recognized in the upper and middle parts of Digma Formation in K.H5\6. This microfacies is equivalent to RMF 5 [19]. This microfacies suggests deposition in the proximal outer ramp paleoenvironment.

6.1.7 Phosclast planktonic peloidal packstone (MF7): This microfacies consists of an abundance of peloids and planktonic foraminifera, such as *Globotruncana* sp. (Pl.3J), *Globotruncanella* sp., *Globotruncanita* sp. (Pl.3K), *Pseudoguembelina* sp., *Hedbergella* sp., *Heterohelix sp*., and *Rugoglobigerina* sp. In addition, there are few benthic foraminifera such as *Bolivina incrassate* (Pl.3L), *Bulimina* sp. (Pl.3M), *Cibicides* sp. (Pl.3N), and *Valvulinoides* sp., along with few shell fragment of mollusca, bioclast, and phosclast (Pl. 1G).

Occurrences: This microfacies is present among four m thickness, recorded in K.H5\6, that represents the late Late Maastrichtian within Digma Formation. This microfacies corresponds to RMF 3 [19]. Phosclast planktonic peloidal packstone microfacies suggest deposition in the proximal outer ramp paleoenvironment.

6.2. Phosclast foraminiferal -dominated mid ramp facies association (FA2)

These facies associations are graded from wackestone to packstone, including three microfacies which are MF8, MF9, and MF10.

6.2.1 Foraminiferal packstone (MF8): This microfacies is distingushed in grey foraminiferal packstone, approximately present in equal proportions of planktonic and calcareous benthic foraminifer's species. It consists of *Globanomalina compressa*, *Praemurica inconstans*, and *Globoconusa daubergensi*. Also, there are fewer percentages of calcareous benthic foraminifera: *Cibicides* sp. (Pl.3O), *Gavelinella danica* (Pl.3P), *Marssonell oxycona* (Pl.3Q), and *Nodosaria* sp..

Occurrences: This microfacies is recognized in the upper part of Akashat Formation in K.H 5\6, which is represented in seven m (Pl. 2A). This microfacies may correspond to the Biozone I in Syria [21] and to RMF 5 [19]. Foraminiferal packstone indicates deposition in high energy distal mid ramp paleoenvironment.

6.2.2 Bioclast foraminiferal packstone (MF9): This microfacies is characterized by abundant benthic foraminifera such as *Anomalinoides* sp., *Cibicides* sp., *Gavelinella pertusa*, *Siphogenerinoides plummerae*, *Valvulinoides* sp., and common bioclasts which are randomly oriented. Two types of bioclast were recognized, phosbioclast and calcibioclast, in addition to small percentages of planktonic foraminiferas, such as *Globotruncana* sp., *Pseudoguembelina* sp., *Hedbergella* sp., *Heterohelix* sp., and *Rugoglobigerina* sp. (Pl.2B).

Occurrences: This microfacies occupies eight m within the middle part of *Pseudoguembelina hariaensis* interval zone, which was recorded in the middle- late Maastrichtian within the Digma Formation in K.H5\6. This microfacies corresponds to RMF3 [19]. This microfacies suggests deposition in high energy distal mid ramp paleoenvironment.

6.2.3 Planktonic phosclast packstone (MF10): This microfacies consists mainly of phosclast in different sizes and shapes, which are mostly rounded to subrounded, with the presence of bone fragments and few planktonic foraminiferas with low percentages of benthic foraminifera (Pl.2C).

Phosphate grains are very common in limestones through most of the intervals of the studied succession, especially in the middle part of Digma Formation in K.H5\6, as well as in the lower, middle, and upper parts of Digma Formation in K.H5\8. Abundant phosphate grains generally indicate very specific geological and paleoenvironmental conditions, such as oxygen deficiency, upwelling conditions, and transgressive intervals [24, 25, 26, 27].

Occurrences: Planktonic phosclast packstone were recognized in two intervals within the lower and upper parts of Digma Formation in K.H5\8 (22 m thick). The matrix of this microfacies in the lower intervals was seen as a micro sparry calcite. This microfacies could be equivalent to Biozones II and III in Syria [21], and may be corresponding to RMF 5 [19]. Planktonic phosclast packstone indicates deposition in proximal mid ramp facies association.

6.3. Quartz phosclast dolomitic- dominated inner ramp facies associated (FA3)

These facies associations are the most dominant lithofacies of the Late Maastrichtian and lower part of Danian in the K.H5\8. These facies are represented by mudstone, grainstone, and floatstone microfacies. Inner ramp facies associations are exemplified by seven microfacies, which are MF11, MF12, MF13, MF14, MF15, MF16, and MF17.

6.3.1 Quartz phosclast grainstone (MF11): This microfacies has limited occurrence. It consists of an abundance of phosclast that have different sizes and shapes, mostly rounded, and could be defined as phosooides. The matrix of this microfacies is silicified in addition to few and small subrounded quartz grains (Pl. 2D).

Occurrences: This microfacies is recognized in three m in the upper part of Tayarat Formation. This microfacies corresponds to RMF29 [19]. It represents an effect of shallowing. Quartz- phosclast grainstone suggest deposition in shallow back- shoal inner ramp facies association. Also the same microfacies occurs in five m in the upper part of Hirri Member of Akashat Formation in K.H5\8, but in Hirri Member, this microfacies does not contain quartz grains and suggest deposition in shoal mid ramp facies association .

6.3.2 Shelly- phosclast floatstone (MF12): This microfacies consists of mollusca shell fragments and occurs at the upper interval of borehole K.H 5\8. It contains an abundance of phosclast (Pl. 2E). This microfacies comprises seven m thickness. It is recognized as Hirri Member of Akashat Formation within borehole K.H5\8. This microfacies is equivalent to RMF 30 and interpreted to be deposited in a shallow back- shoal inner ramp facies association [19].

6.3.3 Phosboney floatstone (MF13): This microfacies consists of micrite matrix with few bone fragments (Pl. 2F). It has 12 m thickness, as recognized in the lower part of the Digma Formation within borehole K.H5\8. This microfacies is equivalent to RMF 24 [19]. Phosbone floatstone indicates deposition in peritidal - shoal inner ramp facies association.

6.3.4 Dolomitic shale\marl (MF14): This microfacies is represented by three m within the middle part of Digma Formation in borehole K.H5\6 and consists of shale\marl that is filled by organic material with a moderate percentage of scattered rhombs of subhedral to euhedral small-sized dolomite crystals. It contains very few planktonic components which are difficult to be identified (Pl.1H). This microfacies is equivalent to RMF22 [19]. Dolomitic shale\marl is interpreted to be deposited in a semi-restricted subtidal -lagoon inner ramp facies association.

6.3.5 Quartz dolomitic mudstone\ wackestone (MF15): This microfacies consists of micrite matrix. Quartz mudstone is barren of any grains and contains channel porosity which is filled by quartz cement (Pl. 2G). This microfacies was introduced to describe three m thickness recognized in the upper part of the Tayarat Formation within K.H5\8. The microfacies is topped by farm ground with Thalassinoides burrows. Quartz dolomitic wackestone was recognized in K.H 5\8 within Tayarat Formation at a depth interval of 190 to160 m. This unit is characterized by dolomite with medium to coarse subangular- rounded bad sorted quartz. This microfacies can be equivalent to RMF 22 [19].It indicates deposition in peritidal inner ramp facies association.

6.3.6 Dolostone inner ramp facies (MF16): This microfacies consists of dolomite only (Pl. 2H) and comprises13 m thickness. It represents the upper part of the Tayarat Formation, along with other 6 m in the middle part of Akashat Formation within K.H5\6. This microfacies is equivalent to RMF 22 [19] and indicates deposition in peritidal inner ramp facies association.

6.3.7 Crystalline limestone inner ramp facies (MF17): This microfacies was recognized in an interval of 4 m within the upper part of the Tayarat Formation and an interval of five m within the upper part of Traifawi Member of Akashat Formation in K.H 5\8. This microfacies indicates deposition in peritidal inner ramp facies association.

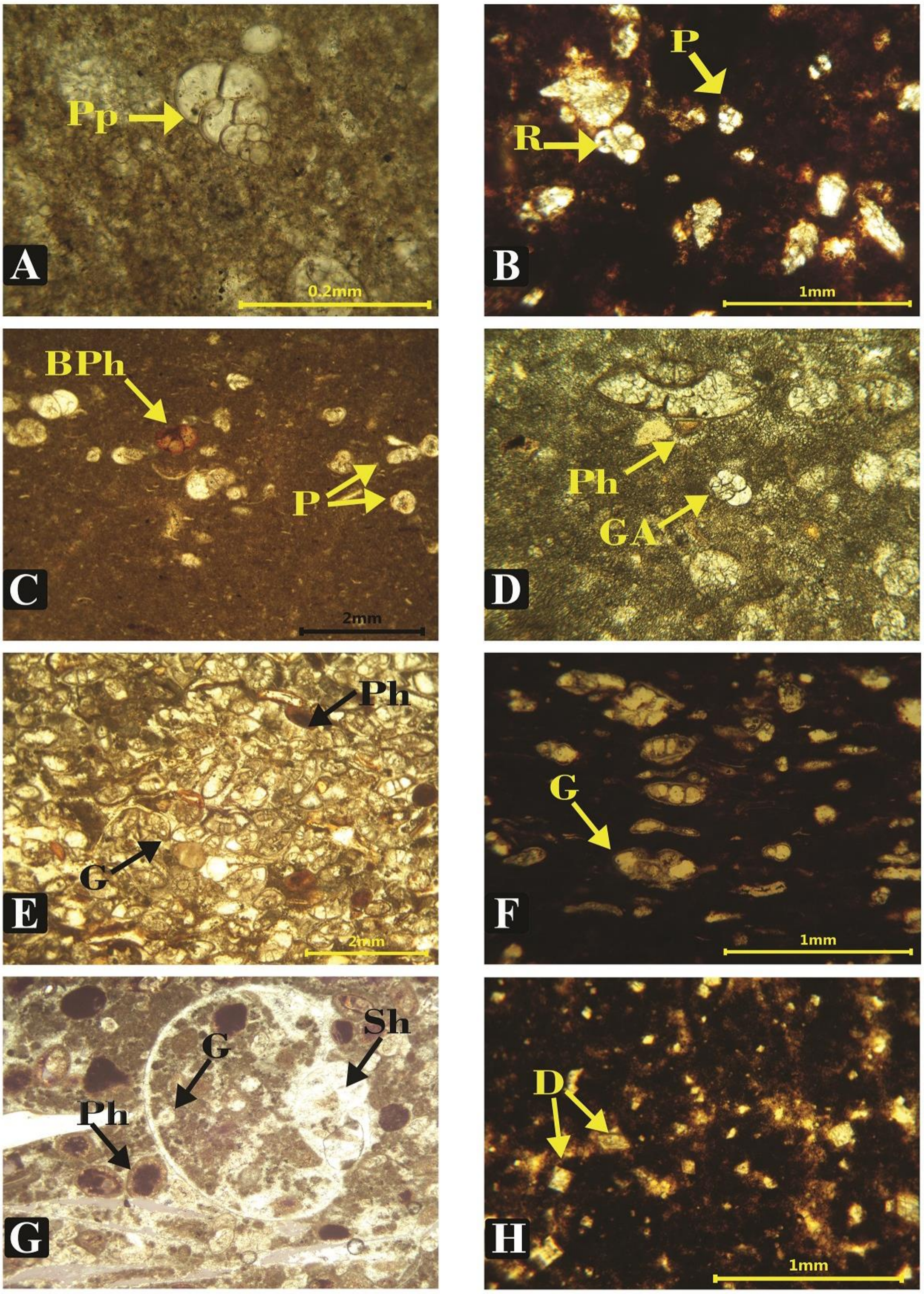

Plate 1- A- Planktonic mudstone; K.H5\6 Digma Formation; (148m). B- planktonic foraminifera black shale\ marl; K.H5\6 Digma Formation; (155m). C- Phosbioclast planktonic wackestone; K.H5\6 Digma Formation; (184m). D- Phosclast planktonic wackestone; K.H5\6 Akashat Formation; (119m). E- Phosclast planktonic packstone; K.H5\6 Digma Formation; (138m). F- phosclast planktonic black shale\ marl; K.H5\6 Digma Formation; (133m). G- Phosclast planktonic peloidal packstone; K.H5\6 Digma Formation; (142m). H- Dolomitic shale\marl;K.H5\6 Digma Formation; (174m). B: Benthic foraminifera, BF: Bone fragment, D: Dolomite, G: *Globotruncana* sp., Gc:*Globanomalina compressa*, , N: *Nodosaria* sp., Pp: *Pseudoguembelina palpebea* P: Planktonic foraminifera, Ph: Phosclast, Q: Quartz graine, R: *Rugoglobigerina* sp., Sh:Shell fragment.

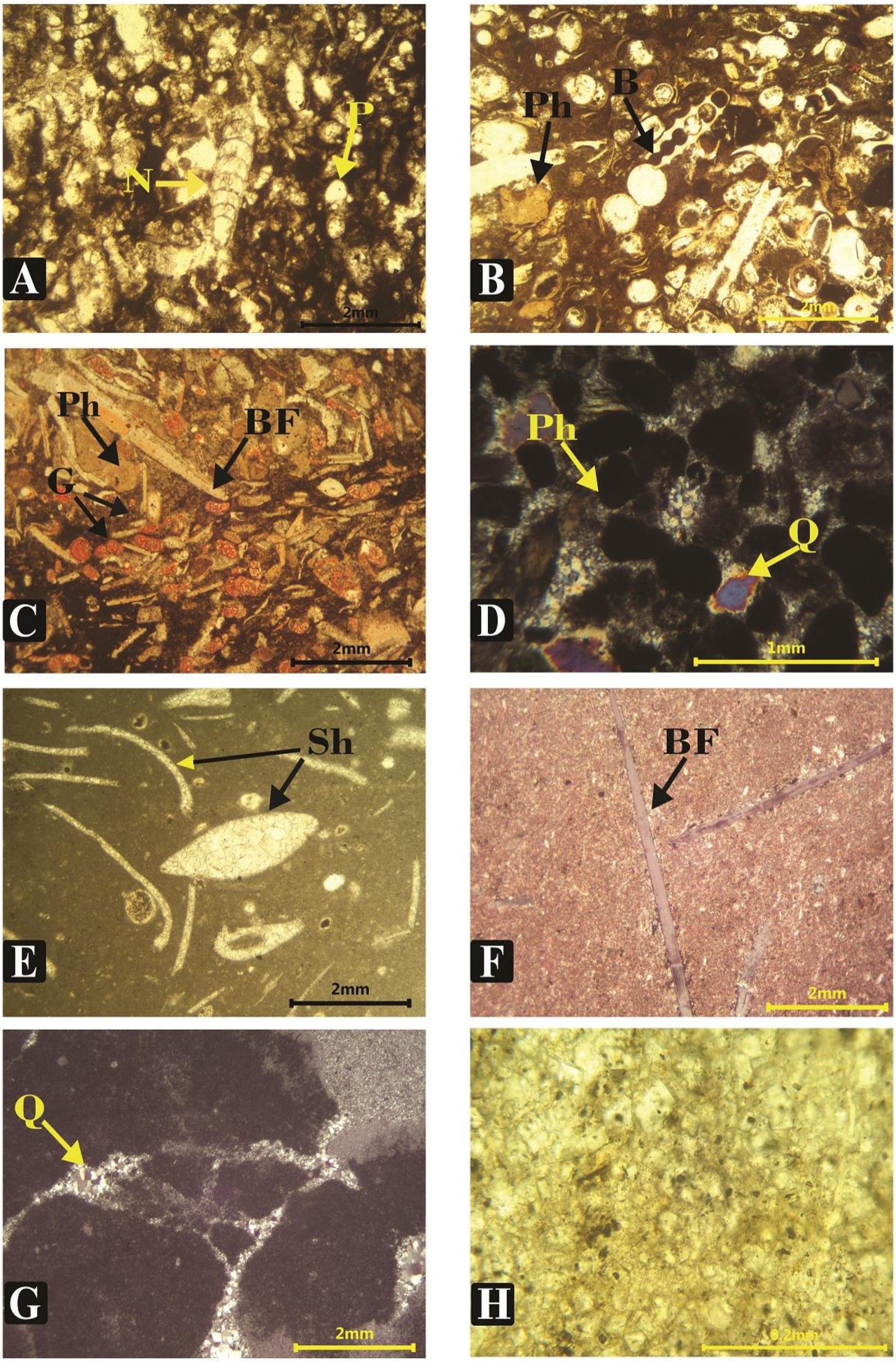

Plate 2- A- Foraminiferal packstone; K.H5\6 Akashat Formation; (107m). B- Bioclast foraminiferal packstone; K.H5\6 Digma Formation; (166m). C- Planktonic phosclast packstone; K.H5\8 Digma Formation; (116m). D- Quartz phosclast grainstone; K.H5\8 Tayarat Formation; (167m). E- Shelly phosclast floatestone; K.H5\8 Akashat Formation; (95m). F- Phosboney floatstone; K.H5\8 Digma Formation; (150m). G- Quartz dolomitic mudstone microfacies; K.H5\8 Tayarat Formation; (164m). H- Dolostone inner ramp microfacies; K.H5\6 Tayarat Formation; (204m).

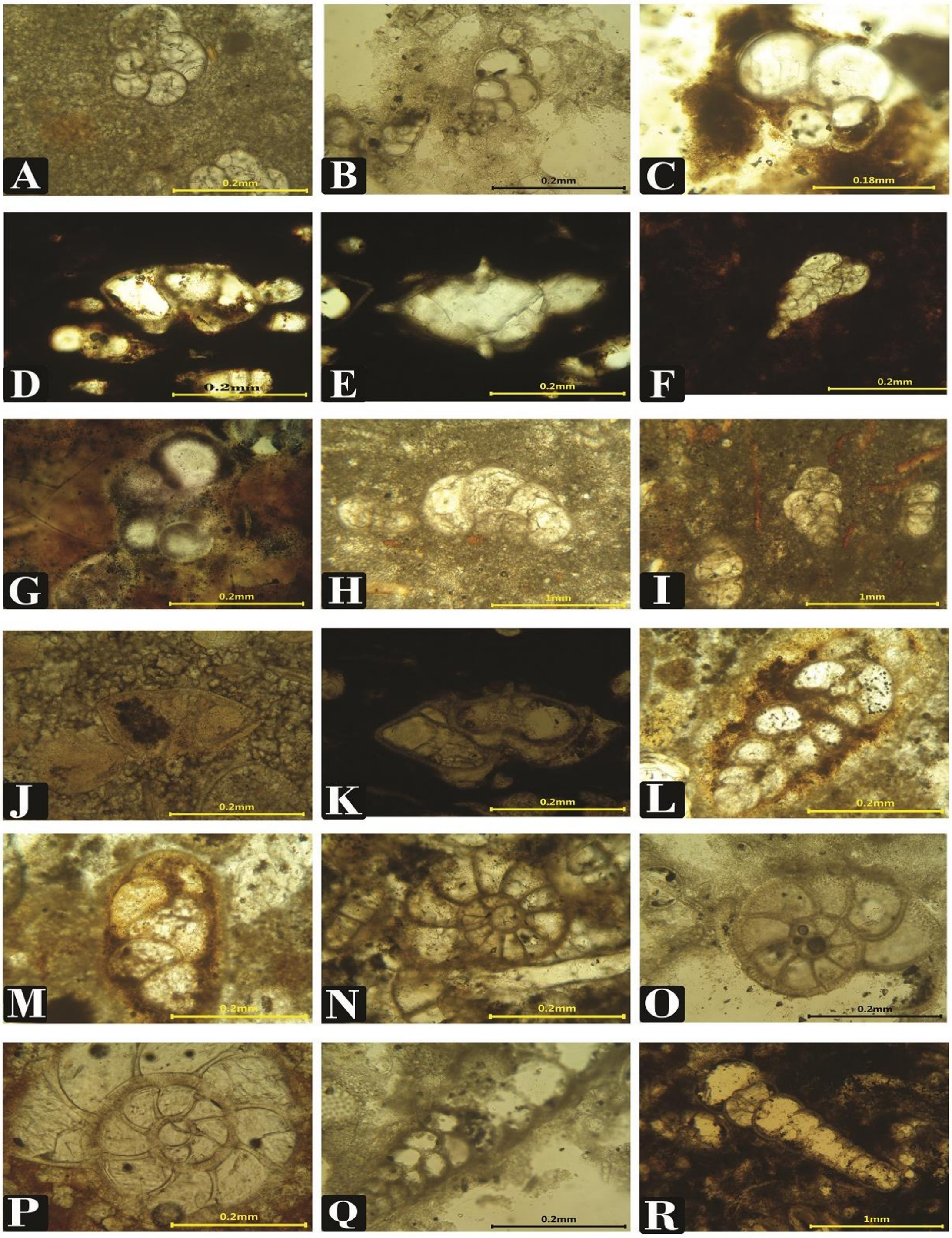

Plate 3-A- *Globanomalina compressa*; K.H 5\6 (109m), B- *Chiloguembelina midwayensi*; Axial section; K.H 5\6;(103m). C- *Eoglobigerina simplicissma*; Equatorial section; K.H 5\6; (104m). D- *Globotruncana arca* ; Subaxial section; K.H 5\6 (153m). E- *Plummerita hantkeninoides*; Axial section;(133m)F-*Guemblitria cretacea* ; Axial section; K.H 5\6;(131m). G- *Parvularugoglobigirina eugubina*;Equatorial section;K.H 5\6;(131.6m). H- *Archaeoglobigerina carteri*; tangential section;K.H5\6(196m)I-*Pseudoguembelina hariaensis*; Axial section;K.H 5\6;(190m). J- *Globotruncana gansseri gansseri*; Axial section; K.H 5\6 (145m). K-*Globotruncanita stuarti*; Axial section;K.H 5\6 (144m). L-*Bolivina incrassata* ; Axial section; (144m)M-*Bulimina aspera*; Axial section; (144m). N- *Valvalabamina lenticular* Reuss; Equatorial section; (140m). O- *Cibicides* sp.; Equatorial section; K.H 5\6;(108m). P- *Gavelinella danica*; Equatorial section; K.H 5\6;(108m). Q- *Marssonell oxycona*; Axial section;K.H 5\6 ;(111m). R-*Nodosaria sp.*; Axial section; K.H 5\6 (105m).

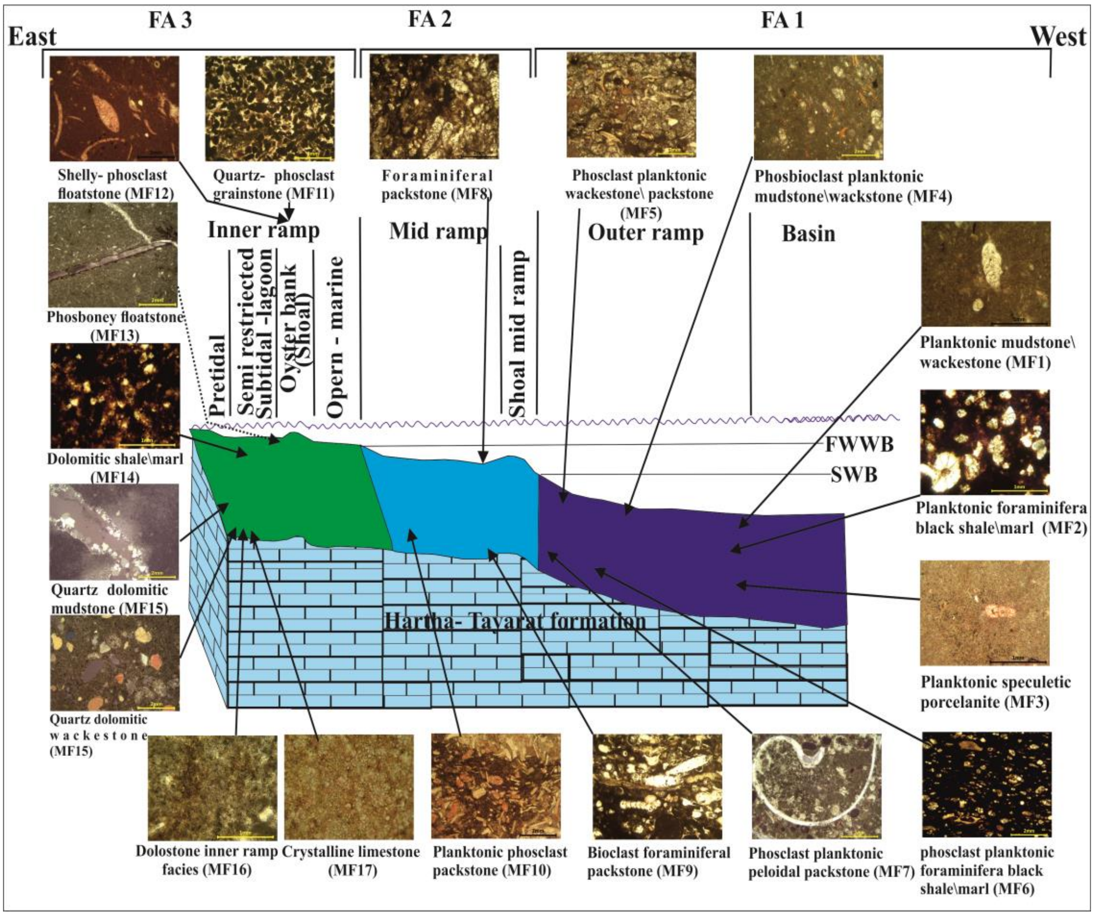

Figure 4- Deposition model of Digma and Akashat formations in the studied sections.

7. Conclusions

A detailed study of the Late Maastrichtian-Early Paleocene facies association was conducted to provide the basis for palaeoenvironmental interpretation of the studied successions. Seventeen microfacies types were classified genetically to yield three facies association**s** that built the lithostratigrphy of Tayarat, Digma, and Akashat formations**;** (1) Phosclast planktonic outer ramp facies association (FA1), which is exemplified in seven microfacies, (2) Phosclast foraminiferal mid ramp facies association (FA2), which included three microfacies, (3) Quartz phosclast dolomitic inner ramp facies association (FA3). The inner ramp facies association is exemplified in seven microfacies. The important microfacies present in borehole K.H 5\6 succession are composed of black shale\marl rich in planktonic foraminifera (MF2) and Black shale\marl with phosclast planktonic foraminifera (MF6), because these microfacies are considered the index fossils of Maastrichtian and Dainan age, and are exemplify by *Plummerita hantkeninoides* and *Guemblitria cretacea*, respectively. Planktonic phosclast packstone (MF10) is the essential microfacies in borehole K.H 5\8 succession because it represents the index fossils of the Late Maastrichtian **(*Plummerita hantkeninoides*)**. The Cretaceous/Palaeogene (K\Pg) boundary is suggested as conformable contact, as there are no breaks in sedimentation and biotic content continues along the successions.The first two facies represent deposition within moderate deep to deep water environment in the mid and outer ramp settings; the latter facies reflected an effect of shallowing and deposition in inner ramp setting. The petrographic analyses of 184 samples were focused on allochem percentage and matrix type. They show that the Maastrichtian- Danian succession deposition took place in a wide variety of depositional environments, ranging from pretidal, lagoon, barrier shoal, and inner to middle ramp environments. The deeper environment is represented by the outer ramp to basinal.

Based on the study of planktonic foraminifera genera at the K.H5\6 and K.H5\8 sections, the identified planktonic foraminifers within the sediments of the Digma Formation are represented by *Globotruncana* sp. and *Globotruncanita* genera, which dominated these sections. It is correlated to

Globogerinoides sp. and *Hedbergella* sp. that reflect a warm water seaway, in connection with the Tethyan realm during the Upper Cretaceous. Therefore, these findings suggest that this section has a close similarity with the planktonic foraminifer's genera in the Tethyan provinces. In the Lower part of Digma Formation of the middle Late Maastrichtian, the presence of *Heterohelix* ssp. and *Rugoglobigerina* spp. can be correlated to the presence of oligotrophic that indicate warm environmental conditions in the lower part of the succession described in borehole K.H5\6.

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