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Microfacies Analysis and Diagenesis Processes of Tanuma Formation for Selected Wells at East Baghdad Oil Field in the Center of Iraq

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Abstract

Khasib Formation was studied in East Baghdad oilfield, Al-Rashdiya area in Baghdad Governorate. The lithology of the formation is limestone throughout the whole sequence in all studied wells (EB-83, EB-87, EB-92, and B94). It is bounded conformably from the top with Tanuma Formation and lower contact with Kifl Formation. The petrographic study shows three main microfacies (lime mudstone, non-laminated peloidal pack-grainstone, and laminated peloidal grainstone) and two submicrofacies (homogeneous non-fossiliferous lime mudstone, bioclast lime mudstone) the study shows the abundance of non-skeletal agains skeletal grains. All microfacies indicate facies zone (7, 8, and 9A) which reflect the platform interior between the open marine to the restricted and evaporitic or brackish water depositional environment. Several diagenesis processes have been distinguished that affected the texture and porosity of Khasib Formation, the most important of which were dissolution, cementation, dolomitization, compaction, micritization, and the porosity of a non-fabric selective type.

Keywords: Khasib Formation, East Baghdad oilfield, Microfacies, Diagenesis processes.

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التحليل السحني والعمليات التحويرية لتكوين تنومة لأبار مختارة من حقل شرق بغداد النفطي، وسط العراق

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الخلاصة

تم دراسة تكوين تنومة في حقل شرق بغداد النفطي، في منطقة الراشدية ضمن محافظة بغداد، يتكون التكوين بشكل أساسي من تتابع الكاربونات الذي المؤلف من الحجر الجيري السجيلي ضمن الآبار الأربعة المدروسة وهي: ,EB-97 EBSZ-1, EBSZ-10 and EBSK-2.11، حيث إن حدود هذا التكوين تتوافق طباقياً من الأعلى مع تكوين السعدي ومن الأسفل مع تكوين الخصيب. الدراسة الصخارية أوضحت وجود ثلاث سُحنات رئيسية ألا وهي: سُحنة الحجر الطيني الجيري ، سُحنة الحجر المرصوص-الحجر الحبيبي غير المتطبق الحاوي على الدمالق وسُحنة الحجر الحبيبي المتطبق الحاوي على الدمالق. تضم سُحن الحجر الطيني الجيري سُحنتين ثانويتين هما: سُحنة الحجر الطيني الجيري ذو الفورامنيفيرا وسُحنة الحجر الطيني الجيري المتجانس الخالي من المتحجرات. أوضحت الدراسة كذلك وجود وفرة عالية من الحبيبات غير الهيكلية مقارنة بالحبيبات الهيكلية ضمن تكوين تنومة في الآبار المدروسة. حيثُ إن كل السحنات الدقيقة تدل على السُحن القياسية (7،8، 9أ) والتي تعكس إن البيئة الترسيبية لتكوين تنومة هي بيئة المنصة الداخلية والتي تقع بين بيئة البحر المفتوح و بيئة المياه المحصورة وتصل الى المياه شديدة الملوحة. اما العمليات التحويرية الاساسية التي اثرت على تكوين التنومة من ناحية النسيج والمسامية فهي: الإذابة، السمنتة، الدلمتة ،المكرتة، والمسامية من نوع النسيج غير الانتقائي الذي يتكون تحت ظروف تكتونية.

الكلمات المفتاحية: تكوين تنومة، حقل شرق بغداد النفطي، السحنات الدقيقة، العمليات التحويرية، السمنتة.

Introduction

During the Cretaceous period (Turonian-Lower Campanian), a carbonate sequence known as the Tanuma Formation was deposited. This conclusion is based on the examination of four specific wells in the East Baghdad Oil Field: EB-97, EBSZ-1, EBSZ-10 (SZ: South Zubair), and EBSK-2-11 (SK: South Khasib). The initial description of the formation was made by Owen and Nasr at well Zubair-3 in Southern Iraq, located at 30°23'01"N and 47°43'29"E, at depths ranging from 2116.8m to 2146.3m.

Tanuma Formation located in the type section has a thickness of 30 meters [1]. This formation is believed to be the result of deposits from a nearshore basin that experienced lagoonal episodes during its formation. Additionally, the formation shows evidence of occasional restricted connectivity with the open sea, as observed through the presence of oolitic limestone and pyrite concentration. The formation was imposed in a restricted shallow basin environment and it includes mainly carbonate succession predominated by black shale with detrital limestone [1].

The formation is impacted by the influx of very fine clastic material from the surrounding land [2]. Due to this, the fossils in the formation are not commonly found. However, [3] reported the presence of Bryozoa and Ostracods in the detrital limestone layers of the formation. [1] indicated that the shale makes up the majority of the formation.

Tanuma Formation contains both skeletal and non-skeletal grains, representing the skeletal grains by benthonic foraminifera and bioclasts. In contrast, the Non-skeletal grain is represented by the peloids. The Late Turonian-Danian megasequence holds utmost importance in Iraq and can be accessed in various regions including the Eastern and Northeastern-West parts of the Hauran Uplift in West Iraq and the internal zones of Zagros Suture. This megasequence was conserved in Southeast Iraq after the ophiolite abduction through reversal. It is noteworthy that this megasequence is present only in the Mesopotamian Zone and the Jezira Subzone. Before the Intra Senonian disintegration, it is possible that the sediment from the Turanian-Early Campanian era was dispersed over a wider area [1].

1. Iraq's deep-shelf sediments comprise the Upper Turonian-Lower Campanian sequence, which also contained the Khasib, Tanuma, and Sa'adia Formations. The middle shelf of the sub-basinal depositional system includes a fine-grained, mixed siliciclastic-carbonate supersequence [4; 5]. In the southwestern regions of the shelf, Tanuma Formation is the second formation in the Turonian-Early Campanian Subcycle. The biggest oil and gas deposits in the Arabian region were created, according to [6], in the East Baghdad Oil Field region due to tectonic activity with regressive and transgression cycles that preserve rich organic matter.The marine and lagoon environments of the southern Tethys Ocean witnessed the deposition of carbonates, shales, and anhydrite in the lithostratigraphic section. These deposits are present in the Cretaceous, Jurassic, and Paleogene eras, which formed gently folded strata in a graben-horst complex that stretches for 100 km from northwest to southeast of Baghdad [7].

2.The investigation aims to identify the microfacies analysis using cutting samples and thin sections of the chosen wells.

3.Location of the study area

According to Iraqi tectonic subdivisions [1], the study area is on the stable shelf within the Mesopotamian Foredeep Basin in the central Iraqi region of the East Baghdad Oil Field, Al-Rashdiya area, and Baghdad Governorate [8] (Table 1, Figure 1).

Table 1: Coordinate the wells, top, bottom, and thickness of the selected wells in the study area (provided by Geological and production data book, 2014).

WELL NO.	COORDINATES		DRILLED DEPTH (M.)	THICKNESS WITHIN THE WELL (M.)
	X	Y		
EB-97	38S 485148.00	3663333	2440-2520	80
EBSZ-1	38S 479861.68	3668764.78	2394-2490	96
EBSZ-10	38S 4764418.91	3670862.01	2386-2476	90
EBSK-2.11	38S 460291.26	3685934.51	2312-2422	110

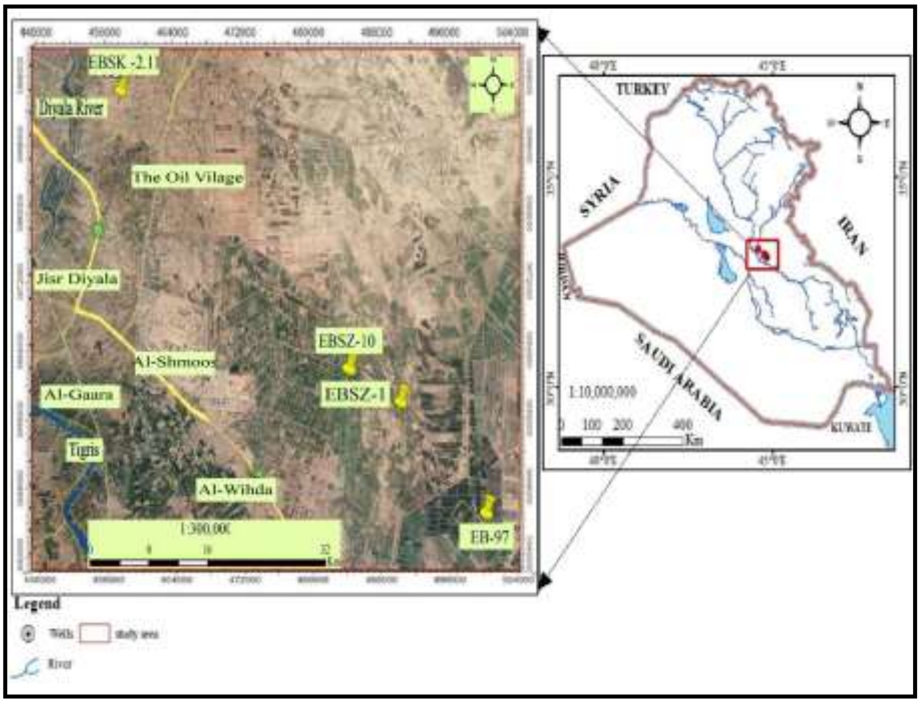

Figure 1: Satellite image shows the location of the studied wells.

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Methodology

Thirty-nine cutting samples were taken from four chosen wells in the East Baghdad Oil Field (EB-97, EBSZ-1, EBSZ-10, and EBSK -2-11).

Thirty-nine thin sections were created in the Petroleum Geology and Minerals Workshop at the University of Diyala's College of Science. A polarized microscope (GXMXPLPOLTEC-2) was used to analyze thin sections to distinguish between the various microfossils' petrographic characteristics. A digital camera (DCE-2) was also used to photograph thin sections.

Tanuma Formation microfacies and depositional environment

Depending to [9], the petrographic texture of the rocks consists of two main components, which are: Particulars (Skeletal and non-skeletal grains), in which the skeletal grains are Transported, fractured, and abraded fossils that become a component of the organic debris were called "skeletal grains" [10]. Aragonite, magnesium calcite, calcite, and dolomite are the typical minerals found in the skeletal grains of carbonate rocks [11]. The phrase "skeletal grains" is used frequently in recent research to refer to fossils visible in thin sections and has a somewhat ambiguous definition in the context of microfacies studies [11].

Skeletal grains may coexist with other forms of carbonate grains, in particular limestone, or they may be the only type of carbonate grains present. These may include whole fossil species, angular fossil fragments, or fragments that have undergone varying degrees of abrasion to smooth them out [10]. Several skeletal grains exist in Tanuma Formation, including foraminifera (benthonic) and bioclasts.

A. Foraminifera

It was noticed the high abundance of foraminifera in the Tanuma Formation within the East Baghdad Oil Field, and the most abundant foraminifera is:

- **Benthonic Foraminifera**

Benthonic Foraminifera represents greater importance for the rocks of the Tanuma Formation. This foraminifera retains its complete shapes, thick walls, and different sizes in most facies; its presence in the Tanuma carbonates indicates a lagoon, shoal, and open marine environment. The most important types of benthonic foraminifera that have been widely distinguished in the formation are:

- **Rotalid**

It is one of the most common benthonic foraminifera in the facies of the Tanuma Formation. Its presence is concentrated in the upper and lower parts, accompanied by the Tanuma shale, with large sizes and thick walls (Fig.2.A).

B. Bioclast

Bioclasts, fragments of fossilized organisms, are produced as a result of biological erosion or compaction factors, which are considered indicators of high energy or mechanical, chemical, and biological crushing under high-energy currents [11]. These bioclasts are representative fragments constituting the significant components, distinguished through the Tanuma Formation in different intervals (Fig.2.B).

While the non-skeletal grains are The main Non-Skeletal grains components distinguished from the thin sections taken from the Tanuma Formation are Ooids and Peloids.

- **Peloids**

Peloids are tiny micritic grains that frequently lack internal organization. They have an uneven form, spherical, ovoid, or sub-rounded shape [11].

Peloids are abundant in deep-water and shallow-marine carbonates such as reef and mud mound carbonates (Fig. 2. C). Pellets are not the only type of marine peloid. Some are thought to be created by the carbonate encrustation of cyanobacterial filaments and endolithic algae [10], the value of peloids as both depositional and paleoenvironmental proxies.

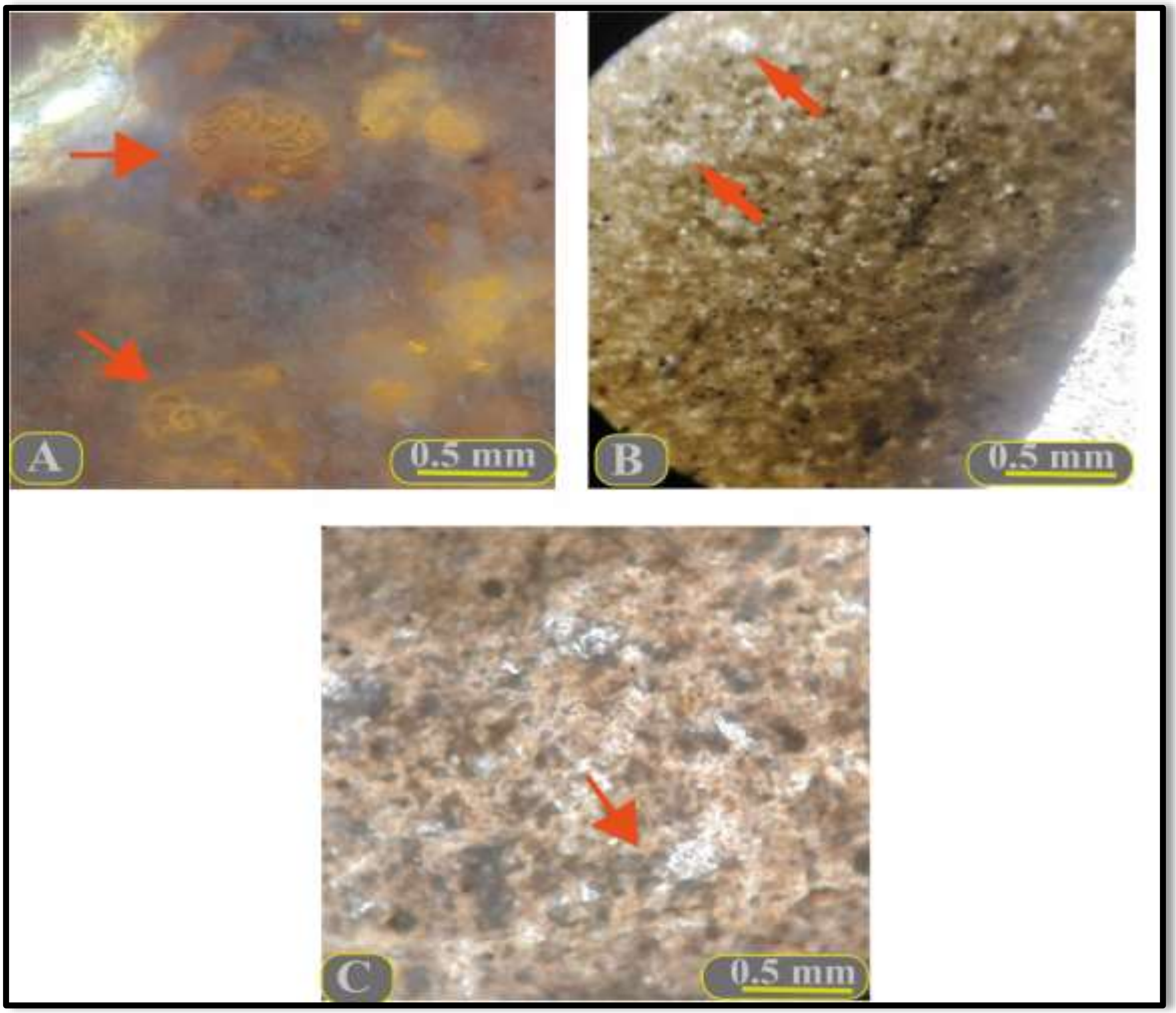

Figure 2: (a). *Rotalia* sp., Benthonic foraminifera, well EB-2.11 at depth (2352-2354) m. (b). Bioclast, well EBSZ-1 at depth (2404-2406) m. (c). Peloids, in well EBSZ-10 at depth (2376-2379) m.

The four wells' accessible thin sections provide information about the carbonate microfacies and the depositional environment of Tanuma Formation. Microfacies study tries to provide a complete inventory of the properties of carbonate rocks (carbonate grain types, types and growth forms of fossils, grain size, shape, nature of micrite, cement, and particle fabrics), which may then be connected to depositional conditions [10], Dunham classification (1962) (Figure 3) and [11] determine the microfacies of the Tanuma Formation inside the investigated wells (Figure 4).

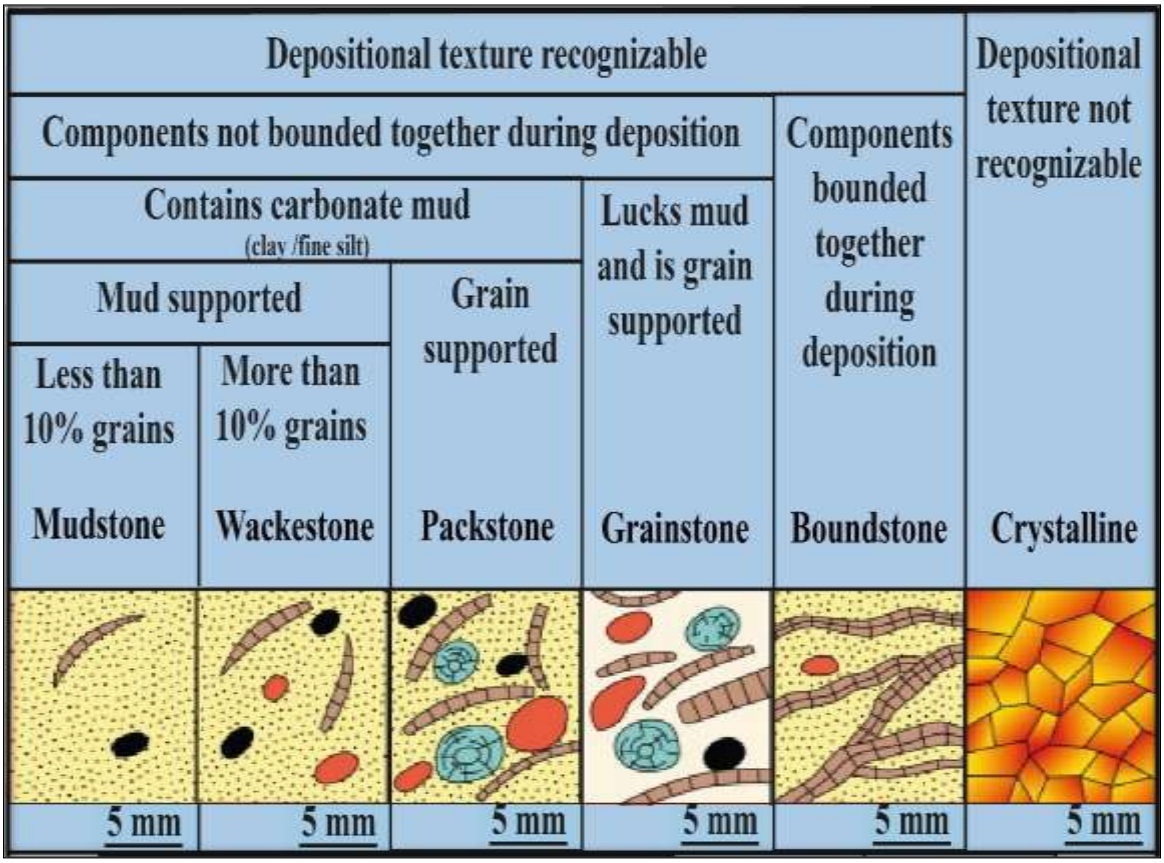

Figure 3: Carbonate rocks classification according to Dunham (1962).

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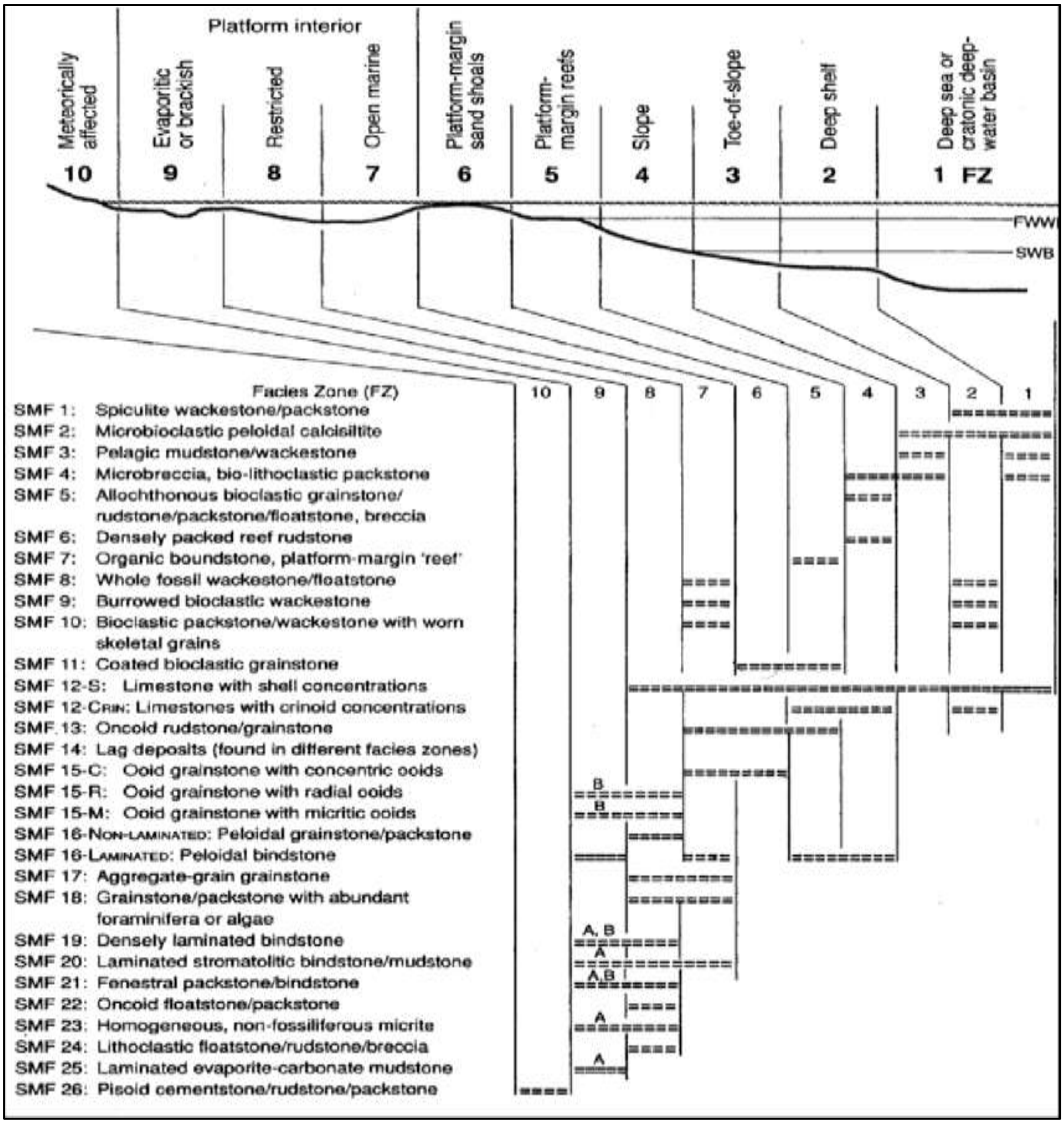

Figure 4: Distribution of standard microfacies (SMF) types in the Facie Zones (FZ) of the rimmed carbonate platform model (Flügel, 2004) (A: evaporitic, B: brackish).

1. Lime mudstone microfacies:

These microfacies is one of the most widespread facies within the sequences of the Tanuma Formation, which contains micrites with a percentage of not less than 90% of its total content and less than 10% of the structural or non-skeletal components [12]. These facies were diagnosed in all wells within Tanuma Formation, as was seen in the formation's upper, middle, and lower portions, as well as in the lower Sa'adi Formation and higher Khasib Formation. These facies come first in terms of their prevalence in the composition. The most abundant presence of these facies is in wells EB-97 and EBSK-2.11. Included two submicrofacies:

A. Homogeneous non-fossiliferous lime mudstone submicrofacies

These sub-microfacies are characterized by a homogeneous micrite, which does not contain any skeletal or non-skeletal components; These sub-microfacies were deposited in the facies zone (FZ-8 and 9A), which constituted the interior of the platform, and are equivalent to standard microfacies (SMF 23) according to [13]. (restricted and brackish), The thickness of these sub-microfacies within the studied wells is a total of 29 m (in well EB-97 is 70; in well EBSZ-1 is 82; in well EBSZ-10, it is 62, and in well EBSK-2.11 is 82) as shown (Fig.5.A).

B. Foraminiferal lime mudstone submicrofacies

These sub-microfacies are characterized by a homogeneous micrite, which does not contain any skeletal or non-skeletal components. These microfacies zones (FZ-8 and 9A) reflect the interior of the platform, and these sub-microfacies are equivalent to standard microfacies (SMF 23) according to [13] (restricted and brackish). The thickness of these sub-microfacies within only one well (in well EBSK-2.11 is 2m). (Fig.5.B)

2. Non-laminated peloidal pack-grainstone microfacies

Microfacies in the current study are located within the upper parts of the formation, only in two studied wells (EBSZ-10 and EBSK-2.11), with a thickness of 17 m; the peloid constitutes approximately 90% of the total non-skeletal grains. It can be compared with standard microfacies (SMF 16) and deposition in the facies zone (FZ-8), which represented the platform interior (restricted) (Fig.5.C and D).The thickness of these microfacies within the studied wells is 18 m. (in well EBSZ-10 is 14 m, and in well EBSK-2.11 is 4 m).

3. Laminated peloidal grainstone microfacies

This microfacies has a percentage of grains (50%) out of its total contents [12]. These microfacies are found in all studied wells and located all over the formation with a thickness of up to 34 m, where the non-skeletal grains are present. It can be compared with standard

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microfacies (SMF-16) and deposition in the facies zone (FZ-7 and 9A) according to [13], which represented the platform interior (open marine, evaporitic or brackish). The thickness of these microfacies within the studied wells is about 29 m (in well EB-97 is 10 m, in well EBSZ-1 is 7 m, in well EBSZ-10 is 10 m, and in well EBSK-2.11 is 2 m).

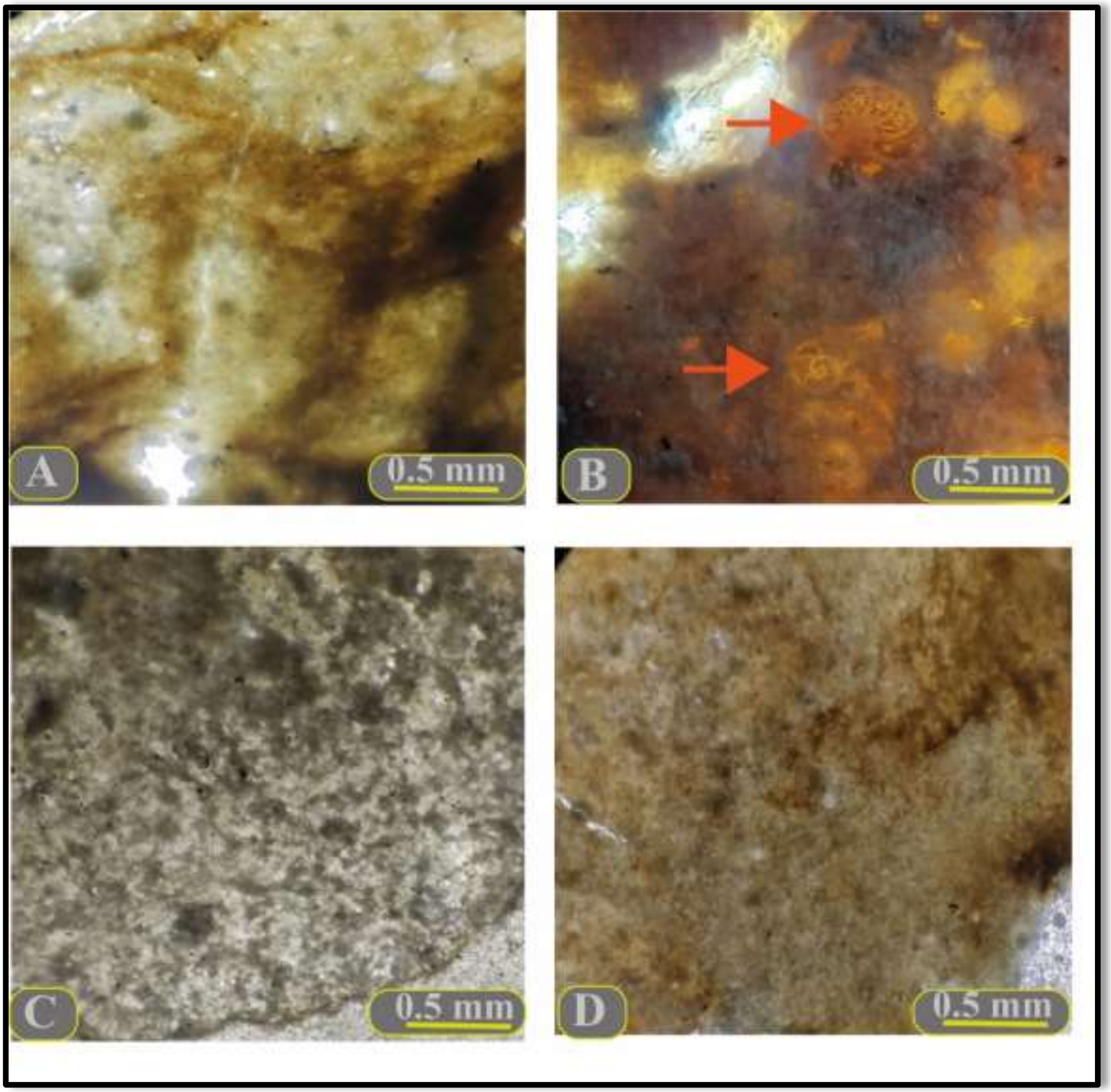

Figure 5: (a). Homogeneous non-fossiliferous lime mudstone sub-microfacies, well EB-97. (b). Foraminiferal lime mudstone microfacies, well EBSK-2.11. (c). Non-laminated peloidal pack-grainstone microfacies, well EBSZ-1. (d). Non-laminated peloidal pack-grainstone microfacies, well EBSZ-10.

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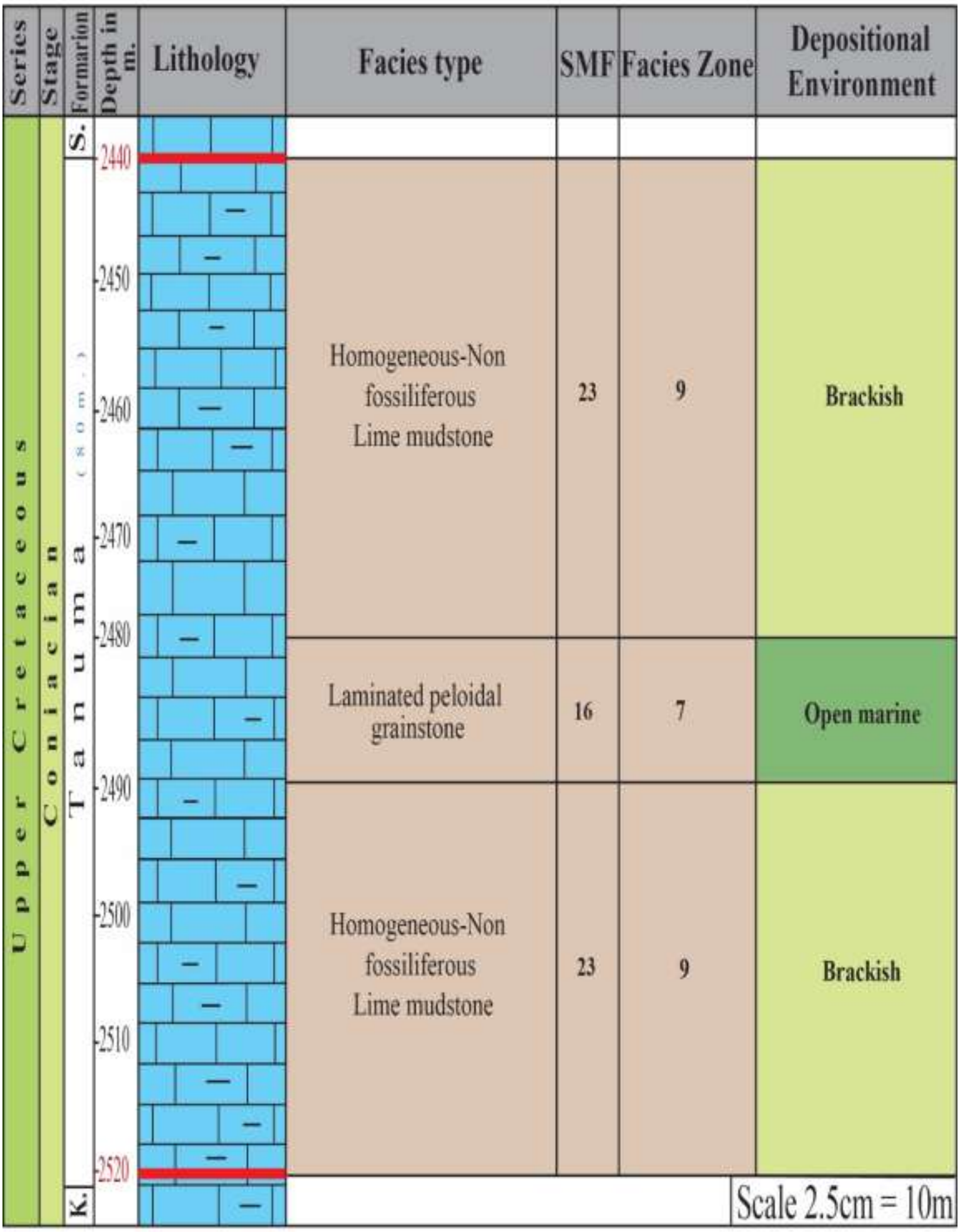

Figure 6: Stratigraphic section showing the microfacies description and depositional environments of Tanuma Formation at well EB-97.

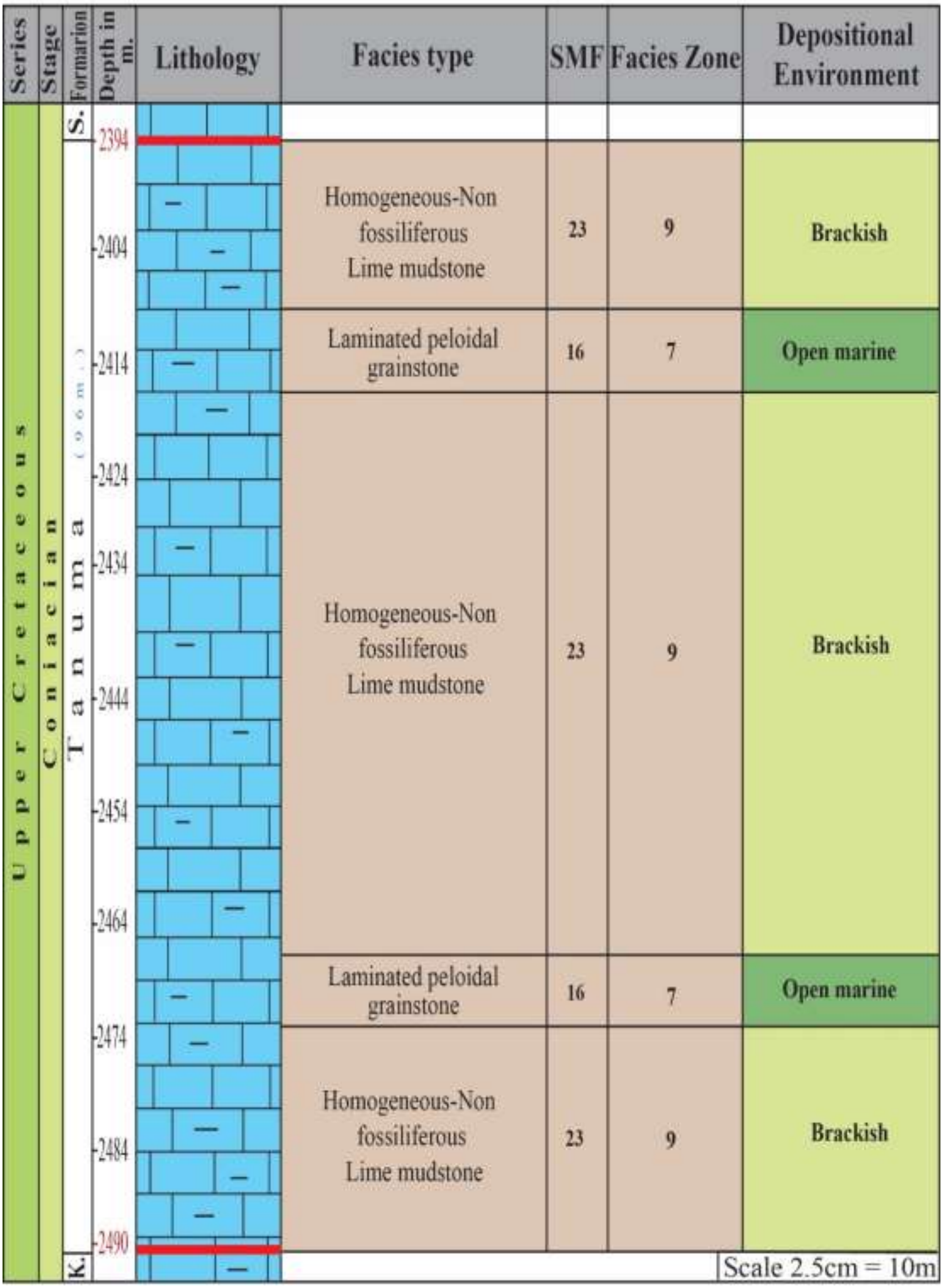

Figure 7: Stratigraphic section showing the microfacies description and depositional environments of Tanuma Formation at well EBSZ-1.

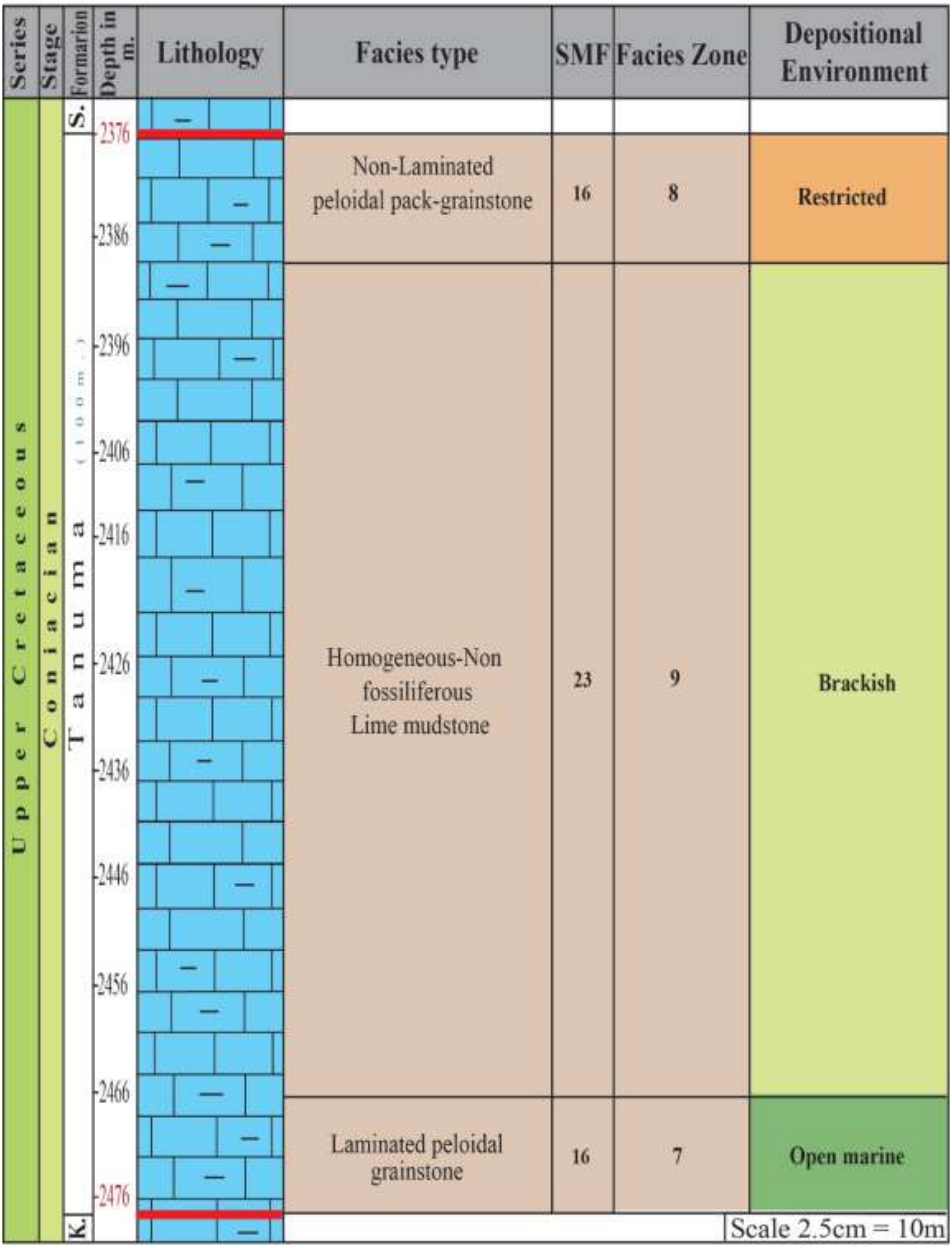

Figure 8: Stratigraphic section showing the microfacies description and depositional environments of Tanuma Formation at well EBSZ-10.

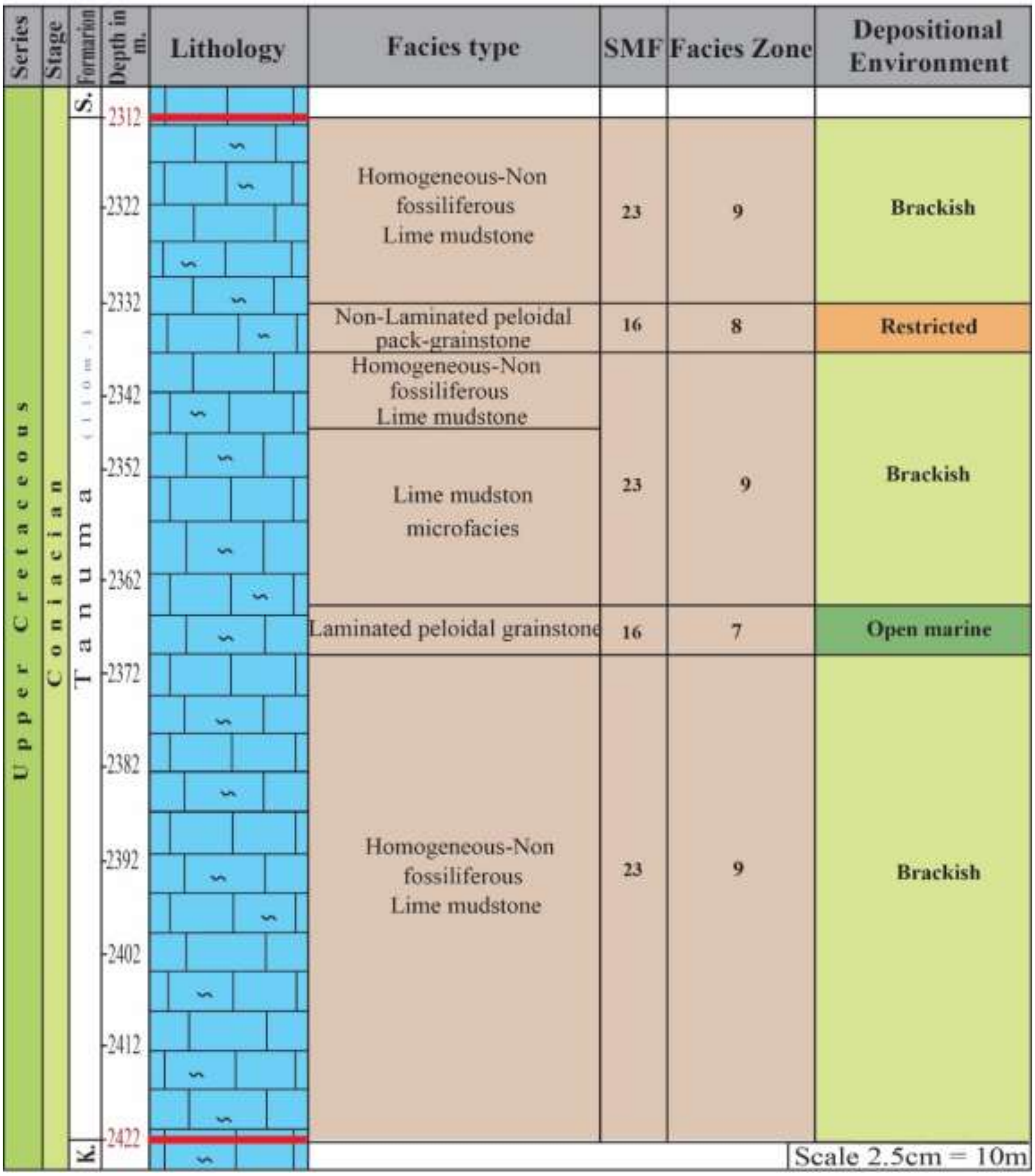

Figure 9: Stratigraphic section showing the microfacies description and depositional environments of Tanuma Formation at well EBSK-2.11.

Diagenesis Processes

All the processes through which unconsolidated sediment becomes a rock are collectively referred to as diagenesis. All textural, physical, chemical, and biological changes to sedimentary rocks that occur both during and after deposition may be included in diagenesis. However, processes involving high temperatures and pressure must not be included in the definition of metamorphism [14]. Diagenesis substantially impacts the final reservoir quality due to the increased likelihood of chemical reactions during burial in carbonate rocks [15]. Numerous processes influenced Tanuma Formation. Micritization, dissolution, recrystallization (neomorphism), dolomitization, compaction, and stylolites are some of the most frequent diagenetic characteristics seen in the sections under study.

A. Micritization:

Particularly in wackestone and packstone textures, the micrite envelope enclosing the entire skeletal organism or the skeletal bioclast represents micritization [16]. This diagenesis process is typical in most study carbonate rocks (Fig.10.A). When the carbonate sediments are deposited, organisms can degrade and break down skeletal grains and other carbonate substances. Because it produces fine-grained sediment, this organic degradation is a sediment-forming process. It is also included here as a very early diagenesis because it modifies previously generated sediment. Deposit is subject to the most significant type of biogenetic alteration due to the boring of organisms' activity. A fundamental process for changing skeletal material and carbonate grains is boring by algae, fungi, and bacteria [10].

B. Dissolution:

Dissolution may occur at any point in the carbonate sequence's burial history after mineral stabilization. The pores created by this non-fabric-selective dissolution pierce through all fabric constituents, including grains, cement, and matrix [17]. These pores are referred to as caves, channels, or vugs, depending on their size [18]. Tanuma Formation experiences an immediate and favorable impact from this process, which increases and forms secondary porosity and permeability, making this formation a significant reservoir. (Fig.10.B).

C. Dolomitization:

Dolomitization is the conversion of limestone or its precursor material to dolomite in whole or in part by the substitution of magnesium carbonate for the original calcium carbonate under the influence of water containing magnesium. When limestone is subjected to the dolomitization process, some of the original depositional texture may be maintained, and dolomitic limestone is partially formed [17].

The micrite's finely dispersed crystalline dolomite rhombs reveal its early-diagenetic origin (early dolomitization). This kind of dolomitization, which happens when sediments precipitate, is uncommon in the current study. Anhedral to euhedral rhomb-shaped medium to coarse dolomite crystals was seen in relation to the pressure solution. In the Middle to lower portions of the Sa'adi Formation, basinal settings frequently contain this kind of dolomite in the Mudstones-Wackstone microfacies. When compaction and cementation processes are absent, Rocks become more porous as a result of late diagenetic dolomitization, which enhances reservoir quality [17]. Intercrystalline secondary porosity, in which dolomite crystals are euhedral to subhedral, appeared to have developed significantly as a result of dolomitization on the characteristics of the rock under study (Fig.10.C).

D. Cementation:

Cementation is one of the chemically homogeneous structural transformation processes, filling primary and secondary pores and filling them with cement materials, which are chemically deposited from saturated solutions. Cement generally consists of calcium carbonate minerals ($CaCO_3$) deposited within the spaces and pores between or inside the grains. [19]. The cementing process takes place in all sedimentary environments. The cement deposited from shallow marine waters is aragonite or high-magnesium calcite (high Mg-Calcite). In contrast, the cement deposited from deep marine waters is low-calcium calcite [20].

In this study, the cementing process was found in all wells where the cement has many types of minerals, such as calcite, dolomite, and pyrite minerals. In the current study, the mineralogy of carbonate cement depends on the quality or composition of the solutions which have passed through these rocks. The most important patterns of cement that were diagnosed within the present study are:

- **Blocky cement:**

Blocky cement consists of large crystals of calcite or dolomite; their crystals are fully faceted, have no direction in growth, and their thickness ranges between (10 microns to a few millimeters) [21]. This type of cement contains high-magnesium calcite or low-magnesium calcite and is found in subterranean environments (vadose and burial environments) and deep environments [11]. In this study, blocky cement occurred accompanied by late diagenesis processes (Fig.10.D).

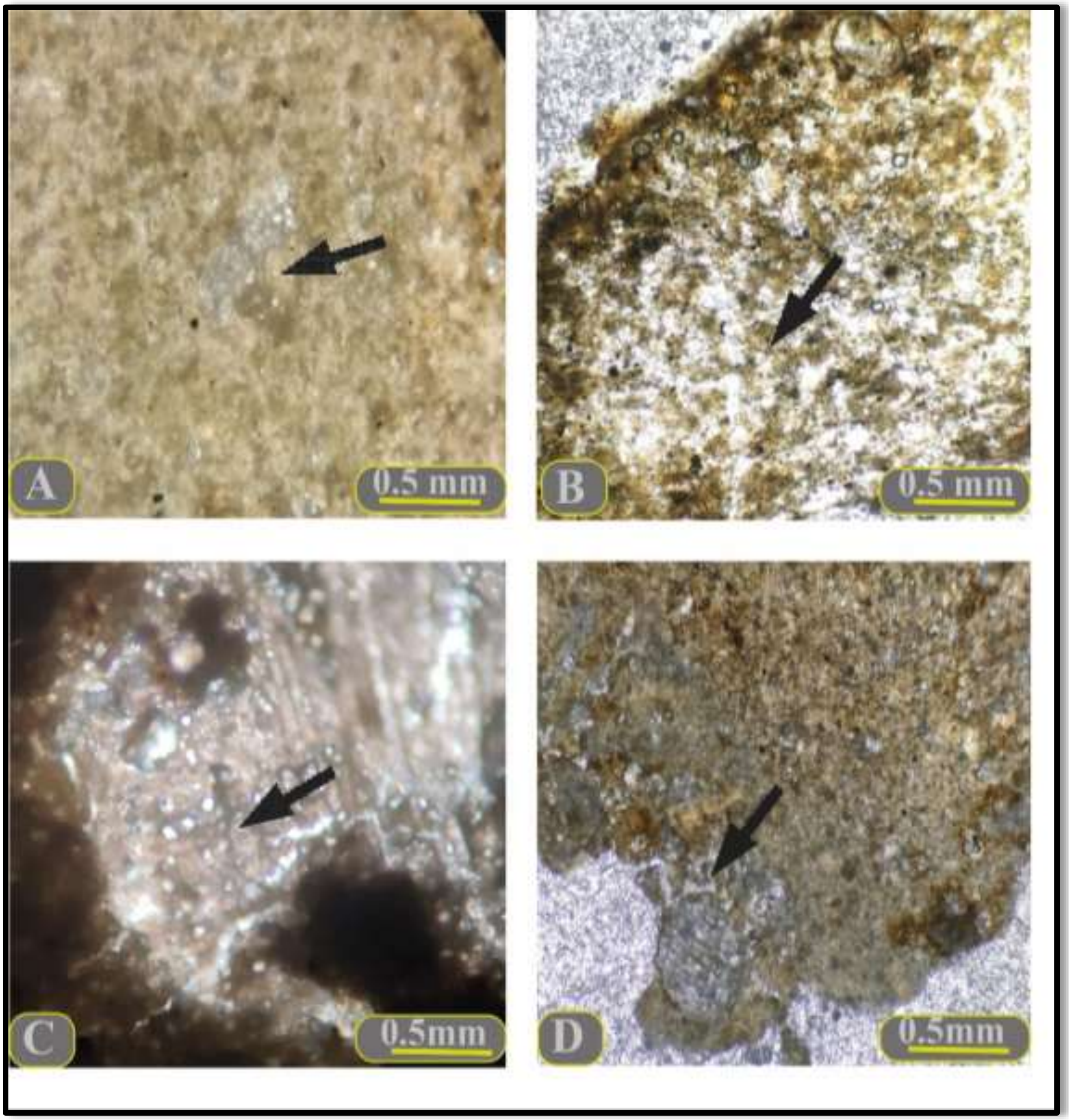

Figure 10: (a). Micritization, well EBSZ-10 at depth (2454-2465) m. **(b).** Dissolution, in well EBSZ-1 at depth (2466-2468) m. **(c).** Dolomitization, in well EB-97 at depth (2500) m. **(d).** Cementation, in well EBSZ-10 at depth (2454-2456) m.

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Conclusions

From this study, the following conclusions can be deduced:

A. Microfacies

1. Non-skeletal grains (Peloid) are more abundant than skeletal grains (rare) in Tanuma Formation in selected wells.
2. Three main microfacies were found: Lime mudstone, non-laminated peloidal pack-grainstone M3, laminated peloidal grainstone M4, and two submicrofacies, which are homogeneous non-fossiliferous lime mudstone M1, Foraminifral lime mudstone sub microfacies M2.
3. Microfacies and the fossil distribution reflect the facies zone (7, 8, and 9A FZ).
4. Tanuma Formation in the present study was deposited in the platform interior between open marine, restricted, and evaporitic or brackish environments.

B. Diagenesis

1. Tanuma Formation is affected by several diagenesis processes: dissolution, cementation, dolomitization, chemical and physical kinds of compaction, and formation of authigenic minerals.
2. Calcite and pyrite are the predominant minerals in the composition of all wells.
3. The formation is affected by several types of non-fabric porosity in all wells, the most important of which are: vuggy porosity, fracture porosity, and channel porosity, which are greatly affected by the two pores (fracture and vuggy porosity).

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