



Petrography, Microfacies, Depositional Environment and Diagenetic Evolution of the Upper Triassic Kurra Chine and Baluti Formations, Northern Iraq

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Abstract:

The Upper Triassic carbonate succession of northern Iraq represents an important record of the northeastern Arabian Plate passive margin and provides valuable information about carbonate platform evolution during the development of the Neo-Tethys Ocean. This study investigates the petrography, microfacies characteristics, depositional environments, and diagenetic evolution of the Kurra Chine and Baluti formations based on detailed microscopic examination of carbonate thin sections from the Ranya and Sirwan sections, northern Iraq. Petrographic analysis reveals that the studied succession is dominated by limestone, dolomitic limestone, and dolostone affected by extensive diagenetic modification. Four major microfacies were recognized in Kurra Chine and six microfacies in the Baluti formation based on carbonate texture, allochem composition, Standard Microfacies (SMF), and Wilson facies zones. The identified microfacies indicate deposition within a shallow homoclinal carbonate ramp extending from restricted lagoonal environments to open lagoon and shoal-margin settings. The Kurra Chine Formation records relatively open inner-ramp conditions, characterized by

transitions from restricted lagoon (FZ8) through open lagoon (FZ7) to shoal-margin environments (FZ6). In contrast, the Baluti Formation represents a more restricted carbonate system dominated by lagoonal conditions with intermittent siliciclastic input and localized open marine influence. Petrographic observations indicate that both formations experienced complex diagenetic histories involving dolomitization, recrystallization, calcite cementation, dissolution, compaction, and fracturing. Dolomitization represents the dominant diagenetic process and played a significant role in modifying primary carbonate fabrics and developing secondary intercrystalline porosity. Dissolution locally enhanced pore development, whereas late calcite cementation and compaction reduced pore connectivity. The results demonstrate that the Baluti and Kurra Chine formations record cyclic changes in depositional conditions related to relative sea-level fluctuations during the Late Triassic. The integration of petrographic and microfacies analysis provides a comprehensive understanding of carbonate platform evolution, diagenetic modification, and reservoir-quality controls within Upper Triassic carbonate successions of northern Iraq.

Keywords: Baluti Formation; Carbonate microfacies; Depositional environment; Diagenesis; Kurra Chine Formation; Northern Iraq; Petrography.

البتروغرافية، والسحنات الدقيقة، والبيئة الترسيبية، والتطور التحويري لترياسي الاعلى لتكويني قوراجين وبلوطي شمال العراق

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الخلاصة:

يمثل التعاقب الكربوناتي للعصر الترياسي المتأخر في شمال العراق سجلاً جيولوجياً مهماً للحواف المستقرة للصفحة العربية الشمالية الشرقية، ويوفر معلومات قيمة عن تطور المنصات الكربوناتية خلال مراحل تطور محيط النيوتيثس. تهدف هذه الدراسة إلى بحث الخصائص البتروغرافية، والسحنات الدقيقة (Microfacies)، والبيئات الترسيبية، والتطورات الدياجينية لتكويني قوراجين وبلوطي، اعتماداً على الفحص البتروغرافي التفصيلي للشرائح الصخرية الرقيقة المأخوذة من مقطعي رانية وسيروان في شمال العراق. حيث أظهرت نتائج التحليل البتروغرافي أن التعاقب الصخري المدروس يتكون بصورة رئيسية من الحجر الجيري، والحجر الجيري الدولوميتي، والدولوستون، وقد تعرض لتأثيرات دياجينية واسعة النطاق. وتم التعرف على أربع سحنات دقيقة في تكوين قوراجين و ست سحنات دقيقة رئيسية في تكوين بلوطي، وذلك استناداً إلى النسيج الكربوناتي، ومكونات الصخور، والسحنات الدقيقة القياس (SMF)، وانطقة السحنات لويلسون Wilson Facies

(Zone) وتشير هذه السحنات الدقيقة إلى أن الترسيب تم ضمن منحدر كربوناتي ضحل من نوع Homoclinal Ramp امتد من بيئات لاجونية مقيدة إلى بيئات اللاجون المفتوح وحافات الضحال (Shoal Margin).

وقد سجل تكوين قورا جين ظروفًا أكثر انفتاحًا ضمن الجزء الداخلي من المنحدر الكربوناتي، تميزت بانتقالات من بيئات اللاجون المقيد (FZ8) إلى اللاجون المفتوح (FZ7)، وصولاً إلى بيئات حافات الضحال (FZ6). على عكس هذا، يمثل تكوين بلوطي نظامًا كربوناتيًا أكثر تقييدًا، سادت فيه البيئات اللاجونية مع تأثيرات متقطعة للرواسب السيليكاتية الفتاتية وبعض التأثيرات البحرية المفتوحة المحدودة. وأظهرت الملاحظات البتروغرافية أن كلا التكوينين قد تعرضا لتاريخ دياجيني معقد شمل عمليات الدولمة، وإعادة التبلور، والإسمنتة بالكالسيت، والإذابة، والانضغاط، والتشقق. وتمثل الدولمة العملية الدياجينية الأكثر تأثيرًا، إذ لعبت دورًا رئيسيًا في تعديل الأنسجة الكربوناتية الأصلية وتكوين المسامية الثانوية بين البلورات. كما أسهمت عمليات الإذابة في تعزيز تطور المسامية محليًا، في حين أدت السمينة المتأخرة بالكالسيت والانضغاط إلى تقليل ترابط المسامات. وتبين النتائج أن تكويني قوراجين وبلوطي يسجلان تغيرات دورية في الظروف الترسيبية ارتبطت بتذبذبات مستوى سطح البحر خلال العصر الترياسي المتأخر. كما أتاح الدمج بين التحليل البتروغرافي وتحليل السحنات الدقيقة فهمًا متكاملًا لتطور المنصة الكربوناتية، والعمليات الدياجينية، والعوامل المتحكممة في جودة المكامن ضمن تعاقبات الكربونات العائدة للعصر الترياسي المتأخر في شمال العراق.

الكلمات المفتاحية: الترياسي المتأخر، السحنات الدقيقة، العمليات التحويرية، تكوين قورا جين، تكوين بلوطي، البتروغرافيا.

1. Introduction:

Petrographic and microfacies analyses constitute fundamental tools in carbonate sedimentology because they provide critical insights into depositional environments, facies architecture, diagenetic evolution, and reservoir characteristics. Petrography focuses on the mineralogical composition, texture, fabric, and diagenetic modifications of sedimentary rocks through microscopic investigation, whereas microfacies analysis integrates petrographic, paleontological, and sedimentological evidence to reconstruct depositional settings and basin evolution [1-3]. The application of microfacies concepts has significantly enhanced the interpretation of carbonate platform systems by enabling the recognition of environmental gradients ranging from supratidal and lagoonal settings to shoal, open-marine, and basinal environments [3]. Carbonate rocks are particularly sensitive to post-depositional alteration, and therefore their present-day characteristics reflect the combined influence of depositional and diagenetic processes. Micritization, cementation, compaction, dolomitization, dissolution, and recrystallization may substantially modify original textures and pore systems, thereby affecting reservoir quality and stratigraphic interpretation [3-4]. Consequently, the integration of petrographic observations with microfacies analysis has become an essential approach for understanding the evolution of carbonate successions and evaluating their geological and economic significance. In northern Iraq, Upper Triassic carbonate–evaporite successions

represent an important record of the northeastern Arabian Plate during the development of the Neo-Tethys Ocean. Among these successions, the Baluti and Kurra Chine formations are of particular significance because they document major environmental fluctuations associated with changes in sea level, platform restriction, and evaporitic conditions [5-6]. The Baluti Formation is characterized by interbedded shale, marl, limestone, dolomitic limestone, and evaporitic deposits, indicating deposition in restricted shallow-marine to lagoonal environments. In contrast, the overlying Kurra Chine Formation consists predominantly of thick carbonate and evaporite successions deposited on a shallow carbonate platform subjected to repeated episodes of restriction and evaporation [6]. Recent investigations have highlighted the complexity of the Kurra Chine depositional system and its significant lateral and vertical facies heterogeneity. Integrated petrographic, sedimentological, and petrophysical studies identified multiple carbonate microfacies deposited within supratidal, intertidal, lagoonal, shoal, and open-marine settings, reflecting cyclic shallowing-upward successions developed on a carbonate ramp system [7-8].

Furthermore, detailed petrographic analyses demonstrated that diagenetic processes, particularly dolomitization, cementation, and dissolution, exerted a major control on pore-system evolution and reservoir properties within the Kurra Chine Formation [8-9]. Recent studies from the Sirwan Valley and subsurface oil fields in northern Iraq also emphasized the importance of petrographic and microfacies investigations for reconstructing depositional environments and understanding reservoir heterogeneity within the Upper Triassic succession [9]. Therefore, a comprehensive petrographic and microfacies investigation of the Baluti and Kurra Chine formations provides valuable information regarding depositional environments, facies distribution, diagenetic history, and paleoenvironmental evolution of the Upper Triassic succession in northern Iraq. Such studies contribute significantly to regional stratigraphic correlations and improve the understanding of carbonate platform development along the northeastern margin of the Arabian Plate. Although several studies have investigated the Upper Triassic carbonate succession in northern Iraq, integrated comparative petrographic and microfacies analyses of both the Kurra Chine and Baluti formations remain limited. Therefore, this study aims to characterize their petrography, microfacies, depositional environments, and diagenetic evolution in the Sirwan and Ranya sections to improve the understanding of the Late Triassic carbonate platform. The objectives of this study are to classify the carbonate microfacies, interpret the depositional environments, identify the principal diagenetic processes, and compare the depositional evolution of the Kurra Chine and Baluti formations.

2. Tectonic setting and structural geology:

The geological evolution of northern Iraq is closely related to the opening and subsequent evolution of the Neo-Tethys Ocean along the northeastern margin of the Arabian Plate. The Neo-Tethys originated as a result of continental extension and rifting associated with the fragmentation of the northern margin of Gondwana during the Middle Permian. This tectonic event led to the separation of the Cimmerian continental blocks from the Arabian Plate and initiated the progressive opening of the Neo-Tethys Ocean, which continued throughout the Triassic and Early Jurassic (ca. 250–160 Ma) [10]. The opening of the Neo-Tethys occurred in two principal tectonic phases. The first phase took place during the Permian–Triassic, when the Iranian microplate drifted northward away from the Arabian Plate toward the Eurasian margin, resulting in the development of an extensional passive continental margin [11–13]. The second phase extended from the Late Triassic to the Middle Jurassic, during which the Neo-Tethys reached its maximum width of approximately 4,000 km. Continued extension along the northern and northeastern margins of the Arabian Plate promoted the development of broad carbonate platforms, restricted intraplate basins, and localized evaporitic environments that characterized the Upper Triassic sedimentary succession in northern Iraq [13] **Figure 1**.

During the Late Triassic, the northeastern Arabian Plate experienced progressive tectonic instability that terminated the long-lasting stable shelf conditions prevailing since the Paleozoic. This instability is reflected by rapid lateral facies variations, localized volcanic activity, syn-sedimentary tectonic movements, and differential subsidence, all of which were closely associated with the continued evolution of the Neo-Tethys Ocean [14]. In the eastern Zagros region, basin development continued into the Early Jurassic (Liassic), reflecting the persistence of extensional tectonics along the passive continental margin [15]. These tectonic events resulted in the formation of a broad restricted intra-shelf basin across northern Mesopotamia, where repeated fluctuations in relative sea level controlled the deposition of carbonate and evaporite successions represented by the Baluti and Kurra Chine formations (Jassim & Goff, 2006) [6].

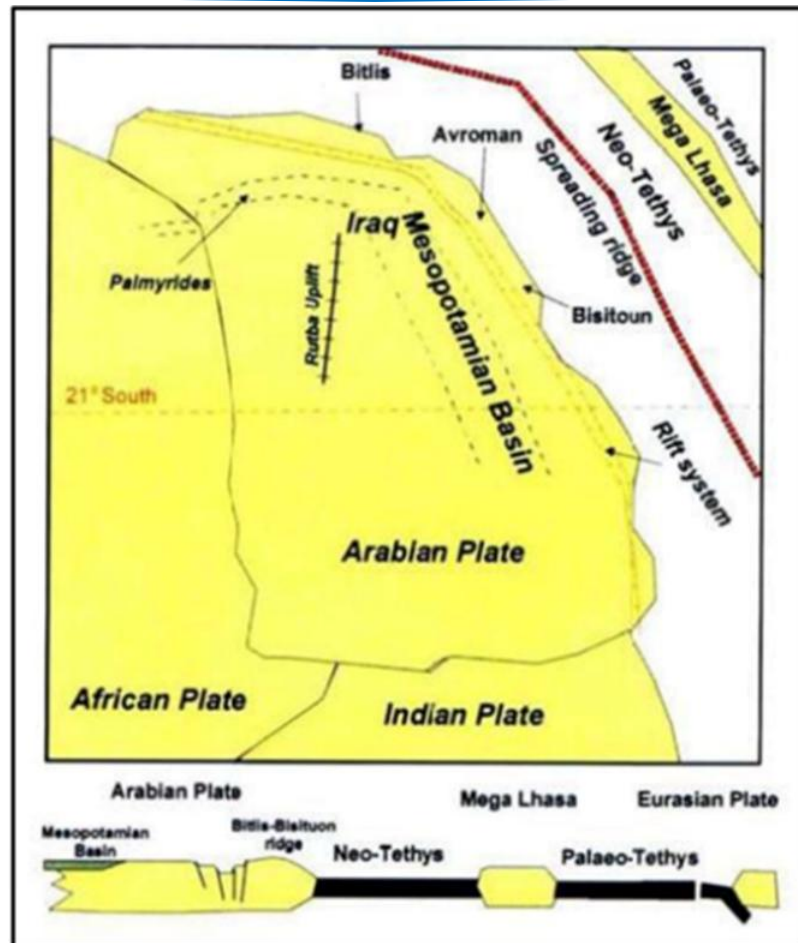


Figure 1: Geodynamic development of Arabian plate during Middle-Triassic-Norian (after [6]).

Structurally, the investigated Sirwan and Ranya sections are situated within the High Folded Zone of the Zagros Fold–Thrust Belt in northeastern Iraq **Figure 2**. This tectonic zone is characterized by NW–SE-trending anticlines and synclines that developed during the Cenozoic collision between the Arabian and Eurasian plates. The present structural configuration has significantly influenced the preservation, exposure, and deformation of the Upper Triassic sedimentary succession within the study area [16].

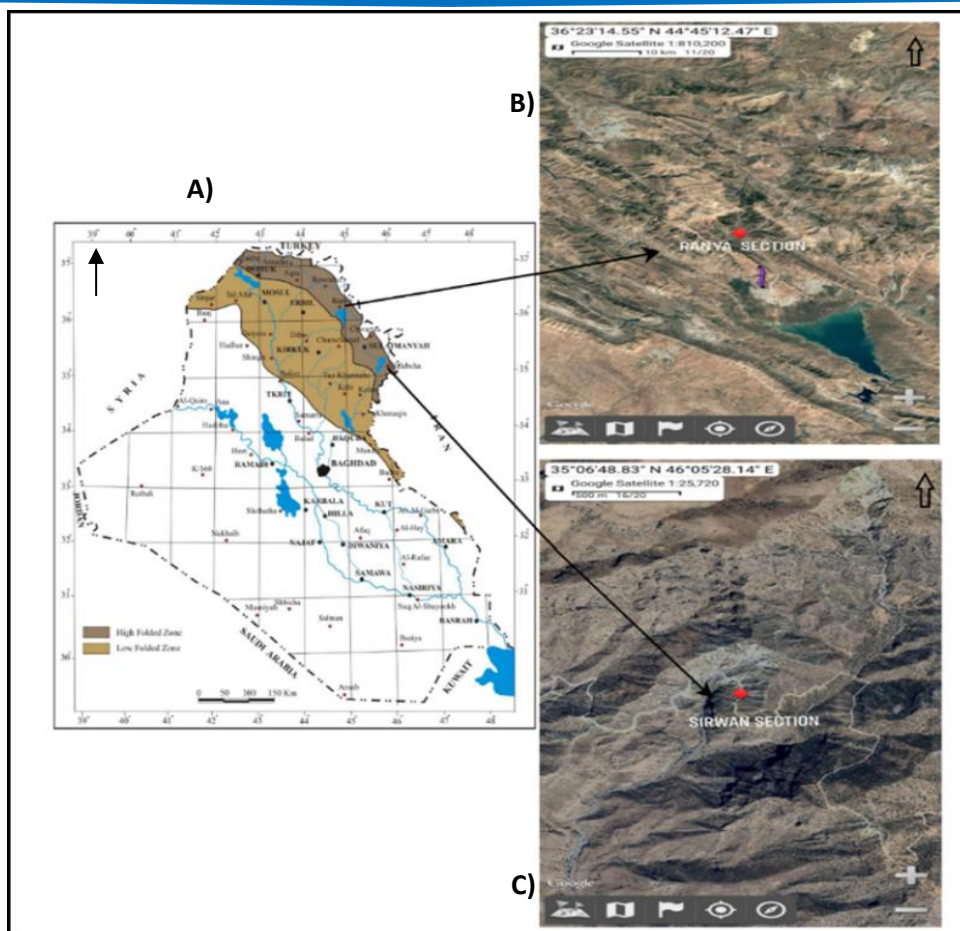


Figure 2: Illustrates the location of the investigated sections. Part (A) presents the regional tectonic position within the High Folded Zone of Iraq after [16], whereas Parts (B) and (C) show Google Earth images of the Ranya and Sirwan sections, respectively.

2. Material and methods:

A total of 11[✓] fresh rock samples were systematically collected from the two sections, the Sirwan Valley section is situated at 46°05'06.32" E and 35°06'34.25" N, whereas the Shawre Valley section lies at 44°44'53.39" E and 36°23'02.19" N **Figure 2 B and C**, including 0⁹ samples from the Sirwan section, which has an exposed thickness of approximately 9[^]m, and 5[£] samples from the Ranya section, where the measured succession is approximately 8⁹.4 m thick. The Sirwan locality is positioned adjacent to the Iraqi–Iranian border, whereas the Shawre section is exposed within the Halabja District of Sulaymaniyah Governorate and represents an Upper Triassic outcrop that has received comparatively limited geological attention. This study integrates field observations with petrographic and microfacies analyses of representative carbonate samples from the Sirwan and Ranya sections. Thin-section petrography, Alizarin Red S staining, and standard carbonate microfacies classification were applied to reconstruct depositional environments and diagenetic evolution. Petrographic and Microfacies analysis study

used a total of 40 thin sections representing limestone, dolomite, dolomitic limestone, and argillaceous dolomite were prepared according to standard petrographic procedures at Tehran University. Petrographic examination was subsequently carried out using a polarizing optical microscope at Al-Kitab University to investigate mineralogical composition, microfacies characteristics, and diagenetic features. To distinguish dolomite from calcite, Alizarin Red S staining was applied to 10 representative samples from both investigated sections following the method of [1^v]. Carbonate microfacies were classified and interpreted according to the schemes proposed by [1] and [3].

4. Results:

4.1 Microfacies Analysis and Depositional Interpretation

The Upper Triassic carbonate succession of the Kurra Chine and Baluti formations was investigated through petrographic analysis and microfacies classification. Based on lithological characteristics, carbonate textures, Standard Microfacies (SMF) types, and Wilson's facies zones [2], several microfacies associations were recognized. These microfacies reflect deposition within shallow homoclinal carbonate ramp systems, ranging from restricted lagoonal settings to open lagoon and shoal-margin environments. The identified microfacies associations indicate that the Kurra Chine Formation was deposited within an inner homoclinal carbonate ramp ranging from restricted lagoonal to shoal-margin environments. The dominance of dolomitic mudstone and dolomitized wackestone reflects protected lagoonal conditions with limited circulation, whereas the occurrence of bioclastic wackestone–packstone indicates intervals of increased marine connectivity and higher depositional energy. The overall facies distribution suggests repeated fluctuations in relative sea level during the Late Triassic, producing alternations between restricted and relatively open marine conditions as illustrate in **Table 1 Figure 3**.

Table 1. Microfacies characteristics of the Kurra Chine Formation

Microfacies	Main Petrographic Characteristics	SMF	Wilson FZ	Depositional Interpretation
MF1: Dolomitic Mudstone	Fine-crystalline dolomite in a mud-supported fabric; rare quartz and calcite-filled fractures.	SMF 23	FZ8	Restricted lagoon; very low energy and limited circulation.
MF2: Dolomitized Wackestone	Micritic matrix with scattered skeletal grains; partial dolomitization and local calcite cement.	SMF 23	FZ7–FZ8	Semi-restricted to protected open lagoon; low–moderate energy.
MF3: Bioclastic Wackestone–Packstone	Abundant skeletal grains in micrite/microspar; locally grain-supported; minor dolomite.	SMF 10–11	FZ6	Open lagoon to shoal margin; higher energy and circulation.
MF4: Recrystallized Dolomitic Limestone	Recrystallized calcite–dolomite mosaic; relict fabrics locally preserved; calcite-filled fractures/cavities.	SMF 23	FZ7–FZ8	Restricted–semi-restricted lagoon; strongly diagenetically modified.

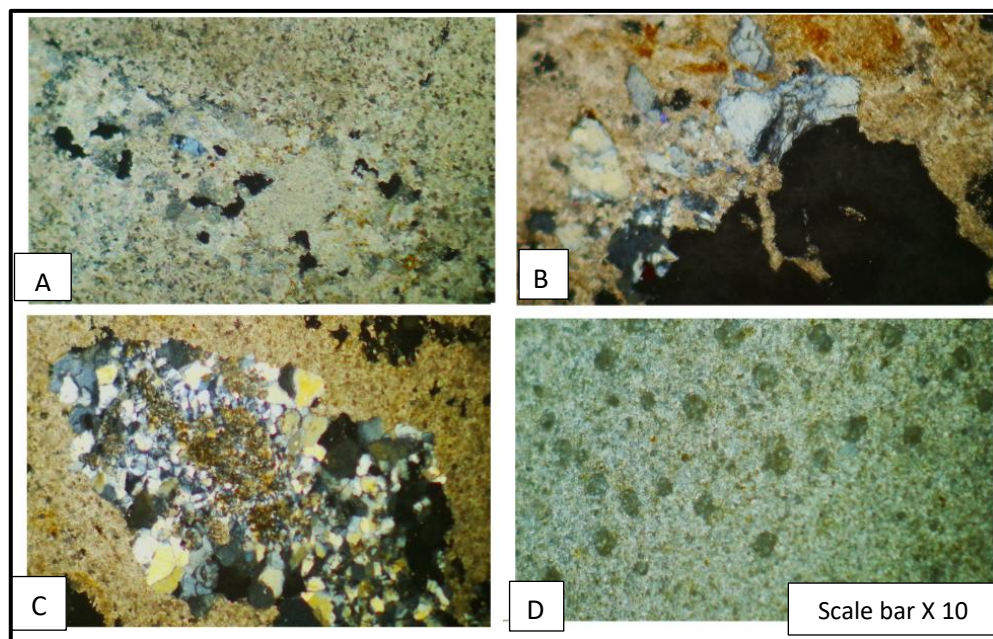


Figure 3: Representative photomicrographs illustrating the identified microfacies of the Kurra Chine Formation. (A) MF1—Dolomitized Mudstone (SK5); (B) MF2—Dolomitized Wackestone (SK10); (C) MF3—Bioclastic Wackestone—Packstone (SK17); (D) MF4— Recrystallized Dolomitic Limestone (RK6).

Interpretation of Baluti Microfacies records deposition within a predominantly restricted inner carbonate ramp. The widespread occurrence of dolomitic mudstone, argillaceous dolomudstone, and dolomitic siltstone reflects low-energy lagoonal conditions with significant siliciclastic influence. In contrast, peloidal–bioclastic wackestone–packstone represents temporary phases of improved marine circulation and increased energy within open lagoon to shoal-margin settings as illustrate in **Table 2 Figure 4**, and recrystallized dolostone is strongly diagenetically modified and therefore provides limited direct evidence for its original depositional setting. The overall facies pattern indicates a more restricted depositional system than the Kurra Chine Formation, with stronger influence from terrestrial input and episodic changes in accommodation space.

Table 2. Microfacies characteristics of the Baluti Formation

Microfacies	Main Petrographic Characteristics	SMF	Wilson FZ	Depositional Interpretation
MF1: Argillaceous Dolomudstone	Dolomicrite with clay, quartz, and feldspar; strong dolomitization.	SMF 19	FZ8	Restricted lagoon with intermittent siliciclastic input.
MF2: Dolomitic Mudstone	Fine-crystalline dolomite with few allochems; local calcite-filled fractures/cavities	SMF 23	FZ8	Restricted lagoon; low energy and evaporative conditions.
MF3: Dolomitized Wackestone	Dolomitized micritic matrix with skeletal grains, peloids, and rare intraclasts.	SMF 18	FZ7	Protected open lagoon; low energy with improved circulation.

MF4: Dolomitic Siltstone	Dolomicritic matrix with abundant fine quartz and minor calcite.	SMF 19	FZ8	Restricted lagoon with periodic siliciclastic influx.
MF5: Peloidal–Bioclastic Wackestone–Packstone	Peloids and skeletal grains in micrite; locally grain-supported; partial dolomitization.	SMF 11	FZ6	Open lagoon to shoal margin; relatively higher energy.
MF6: Recrystallized Dolostone	Medium–coarse dolomite; original fabric largely destroyed; calcite-filled fractures/cavities.	SMF 23	FZ8–FZ9	Restricted lagoon to supratidal; intense diagenetic alteration.

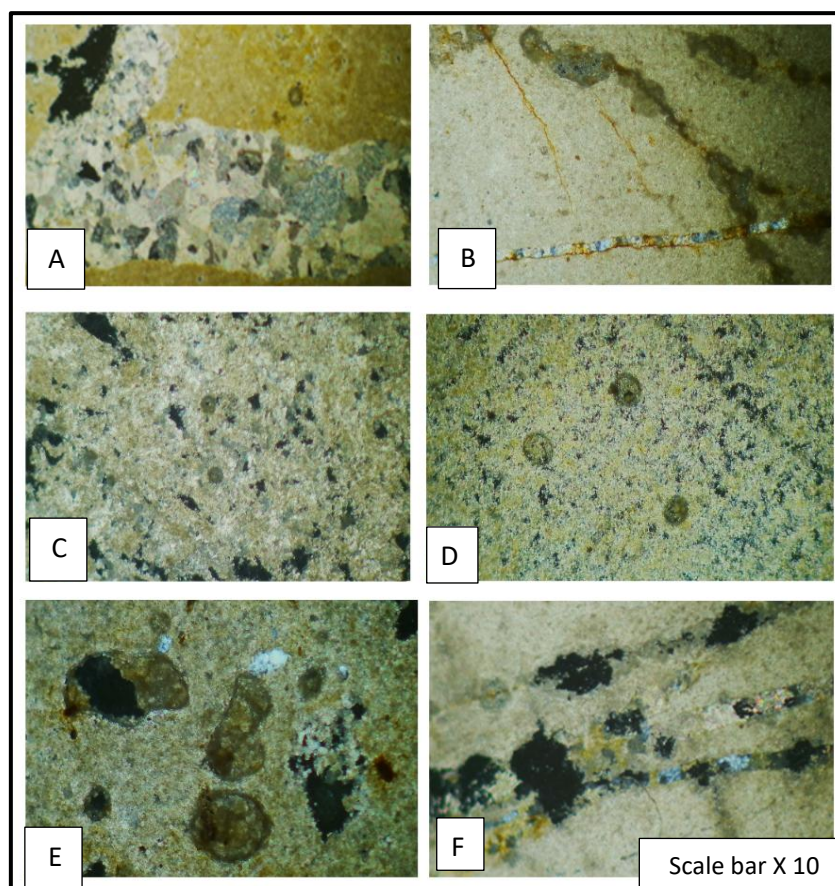


Figure (4): Representative photomicrographs illustrating the identified microfacies of the Baluti Formation. (A) MF1—Argillaceous Dolomudstone (RB2); (B) MF2—Dolomitic Mudstone (SKB30); (C) MF3—Dolomitized Wackestone (SKB27); (D) MF4—Dolomitic Siltstone (RB10); (E) MF5—Peloidal–Bioclastic Wackestone–Packstone (SKB21); (F) MF6—Recrystallized Dolostone (SKB28).

4.2 Diagenetic Processes of the Kurra Chine and Baluti Formations

Both the Kurra Chine and Baluti formations experienced complex diagenetic histories involving marine, meteoric, and burial processes that significantly modified the original carbonate fabrics and influenced their pore systems. The main diagenetic processes recognized include dolomitization, recrystallization, calcite cementation, dissolution, compaction, fracturing, and development of secondary intercrystalline porosity **Figures 5 and 6**.

Dolomitization represents the dominant diagenetic process affecting both formations. Petrographic observations reveal partial to pervasive replacement of micritic limestone by fine- to medium-crystalline dolomite, forming anhedral to subhedral crystal mosaics that commonly obscure primary textures. The widespread occurrence of dolomite within restricted lagoonal microfacies suggests early dolomitization under evaporative conditions through interaction with Mg-rich hypersaline fluids. Subsequent burial processes promoted dolomite recrystallization and further modification of the carbonate fabric.

Recrystallization accompanied dolomitization and burial alteration, transforming micritic carbonate material into microspar and coarse crystalline mosaics. This process partially destroyed original depositional textures while preserving some relict fabrics, particularly within dolomitized and recrystallized microfacies of both formations.

Calcite cementation was an important late diagenetic process, with sparry calcite commonly filling fractures, dissolution cavities, and intercrystalline pore spaces. Although cement precipitation stabilized the carbonate framework, it reduced secondary porosity by occluding pore networks. Dissolution played a significant role in modifying the pore systems by generating vuggy, moldic, and enlarged fracture porosity through selective removal of unstable carbonate components. The partial filling of dissolution cavities by sparry calcite indicates that dissolution preceded late-stage cementation and was related to the circulation of meteoric or burial fluids.

Compaction and fracturing affected both formations during burial and tectonic evolution. Mechanical compaction resulted in grain rearrangement and reduction of primary pore spaces, whereas chemical compaction produced pressure-solution features and localized stylolites. Micro- and macrofractures commonly cut carbonate fabrics and diagenetic minerals and were frequently filled with coarse crystalline calcite, indicating deformation prior to the final cementation stage. These fractures also enhanced fluid migration and facilitated subsequent diagenetic alteration.

Development of intercrystalline porosity represents the most significant secondary pore type associated with dolomitization. Replacement of the original carbonate matrix by dolomite generated pore spaces between dolomite crystals, locally forming interconnected pore networks. This porosity is particularly well developed in highly dolomitized intervals of both formations, including samples SK4, SK5, RB2, and SKB30. However, later calcite cementation locally reduced pore connectivity.

Overall, diagenetic evolution of the Kurra Chine and Baluti formations reflects a balance between porosity-enhancing processes, mainly dolomitization and dissolution, and porosity-reducing processes, including cementation, compaction, and recrystallization. These interactions controlled the final petrographic characteristics and reservoir potential of the Upper Triassic carbonate succession in northern Iraq.

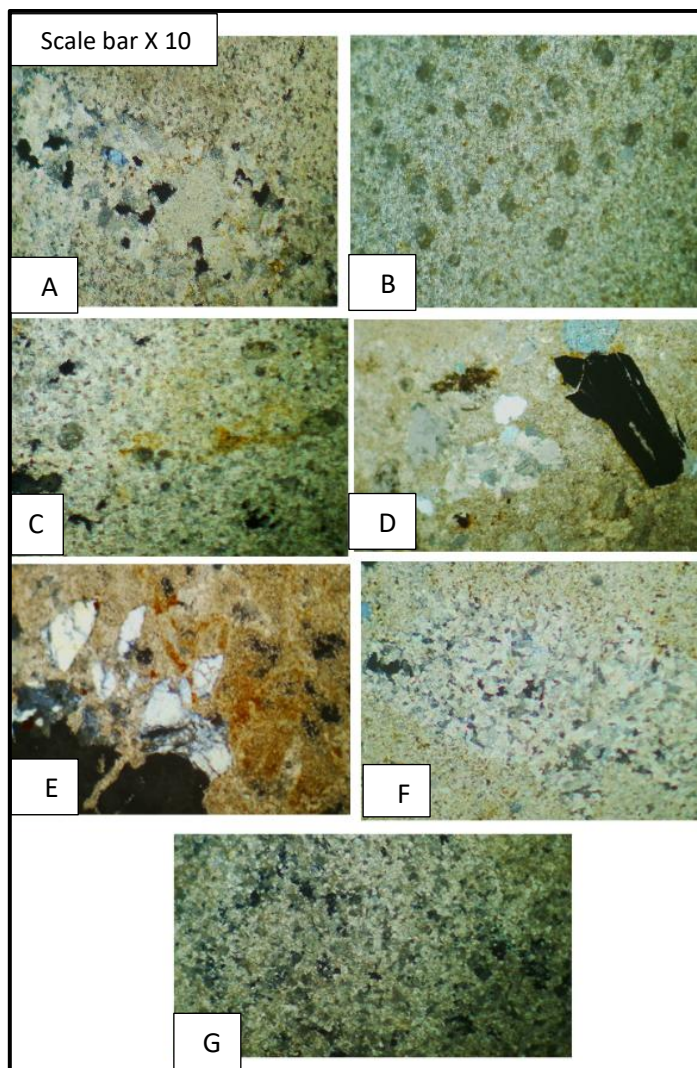


Figure (5): Representative photomicrographs illustrating the main diagenetic processes in the Kurra Chine Formation: (A) dolomitization (SK5); (B) recrystallization (RK6); (C) calcite cementation (SK17); (D) dissolution (RK3); (E) fracturing (SK10); (F) mechanical compaction (SK20); and (G) intercrystalline porosity (SK4).

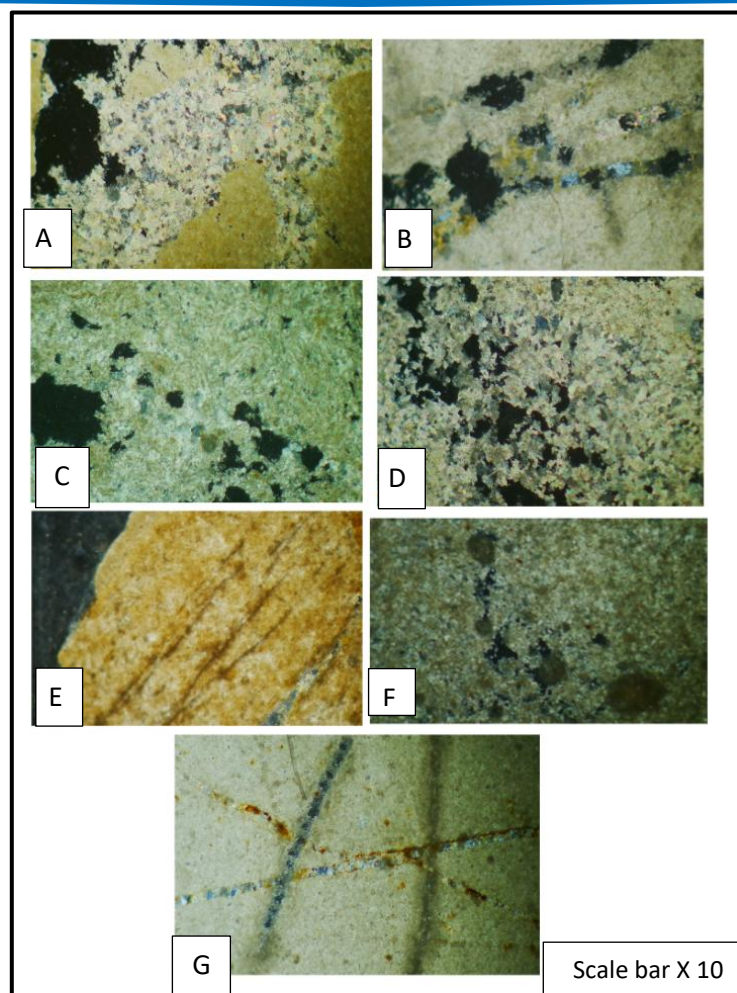


Figure 6: Representative photomicrographs showing the principal diagenetic processes affecting the Baluti Formation: (A) dolomitization (RB2); (B) recrystallization (SKB28); (C) calcite cementation (SKB27); (D) dissolution (SKB21); (E) compaction (SKB26); (F) fracturing (SKB24); and (G) Intercrystalline porosity (SKB30).

4.3 Depositional Environment

The microfacies associations of the Kurra Chine and Baluti formations indicate deposition within shallow homoclinal carbonate ramps developed along the passive margin of the Neo-Tethys Ocean during the Late Triassic. The recognized facies reflect a spectrum of depositional environments ranging from restricted lagoonal settings to open lagoon and shoal-margin environments, primarily controlled by relative sea-level fluctuations and variations in marine circulation. The Kurra Chine Formation records a relatively open depositional system. Dolomitic mudstone (MF1) represents restricted lagoonal conditions (FZ8) characterized by low hydrodynamic energy, limited circulation, and elevated salinity that promoted early dolomitization. Dolomitized wackestone (MF2) reflects improved marine circulation within semi-restricted to open lagoon settings, whereas bioclastic wackestone–packstone (MF3) records the highest depositional energy in open lagoon to shoal-margin environments (FZ6).

Recrystallized dolomitic limestone (MF4) represents lagoonal carbonates extensively modified by post-depositional diagenesis.

In contrast, the Baluti Formation represents a more restricted depositional system dominated by lagoonal conditions. Dolomitic mudstone (MF1), argillaceous dolomudstone (MF2), and dolomitic siltstone (MF4) indicate low-energy restricted lagoonal environments influenced by intermittent siliciclastic input from nearby continental sources. Dolomitized wackestone (MF3) reflects protected open-lagoon conditions, whereas peloidal–bioclastic wackestone–packstone (MF5) records temporary increases in depositional energy within open lagoon to shoal-margin settings. Recrystallized dolostone (MF6) reflects extensive diagenetic modification rather than a distinct depositional environment. Overall, both formations were deposited within an inner carbonate ramp; however, the Kurra Chine Formation records greater marine connectivity and more frequent transitions toward open lagoon and shoal environments, whereas the Baluti Formation reflects predominantly restricted lagoonal deposition with stronger siliciclastic influence and local supratidal conditions. The vertical facies succession in both formations indicates repeated Late Triassic relative sea-level fluctuations that controlled facies distribution across the carbonate platform.

5. Discussion

5.1 Depositional Evolution of the Kurra Chine Formation

The microfacies of the Kurra Chine Formation indicate deposition on a shallow homoclinal carbonate ramp along the northeastern Arabian Plate during the Late Triassic. The transition from restricted lagoonal dolomitic mudstone to open-lagoon and shoal-margin bioclastic facies reflects variations in marine circulation, depositional energy, accommodation, and relative sea level. The dominance of dolomitic mudstone (MF1) and dolomitized wackestone (MF2) indicates low-energy, restricted lagoonal conditions where evaporation favored dolomitization [4];[18]. The preservation of original wackestone fabrics within partially dolomitized MF2 suggests that dolomitization partly occurred early, followed by recrystallization during burial [^]. Bioclastic wackestone–packstone (MF3) records improved marine circulation and relatively higher-energy conditions, representing a transition toward open-lagoon and shoal-margin settings. This interpretation agrees with previous studies that recognized a range of inner-, middle-, and locally outer-ramp environments in the Kurra Chine Formation [7].

However, the Sirwan and Ranya sections are dominated mainly by restricted inner-ramp facies, with episodic development of more open and higher-energy conditions. The vertical facies succession reflects variations in accommodation, hydrodynamic energy, marine circulation, and degree of restriction, consistent with the regional sequence-stratigraphic framework of the Arabian Plate [19-20] further highlighted the regional significance of the Carnian “Marker Dolomite” and its relationship to the Baluti Formation. Recent studies also demonstrate substantial facies and diagenetic heterogeneity within the Kurra Chine Formation, which strongly influences reservoir quality [^]. Accordingly, the present study indicates that the studied sections mainly record restricted inner-ramp conditions interrupted by episodes of enhanced marine circulation and higher-energy deposition.

5.2 Depositional Evolution of the Baluti Formation

The Baluti Formation records deposition within a restricted inner-ramp carbonate system influenced by intermittent siliciclastic input. Dolomitic mudstone, argillaceous dolomudstone, and dolomitic siltstone indicate low-energy lagoonal conditions, whereas peloidal–bioclastic wackestone–packstone (MF5) reflects short intervals of improved marine circulation and higher depositional energy. Compared with the Kurra Chine Formation, the greater abundance of quartz and argillaceous material indicates stronger terrigenous influence, probably related to proximity to continental sources and/or enhanced terrestrial runoff [5-6].

Edilbi et al. [21] recognized supratidal, intertidal, subtidal, lagoonal, and shoal microfacies within the Baluti Formation. Mud-rich facies indicate protected, low-energy conditions, whereas peloids, ooids, intraclasts, and fenestral structures indicate episodic increases in depositional energy. Asaad et al. [22] similarly documented a heterogeneous succession of dolomitic limestone, marly limestone, shale, and marl, supporting deposition under changing rather than uniform environmental conditions. The greater abundance of argillaceous and siliciclastic material in Baluti represents an important distinction from Kurra Chine and indicates stronger terrestrial influence and restriction. Edilbi et al. [21] also reported terrestrial organic-matter input and locally anoxic to suboxic conditions. Lunn et al. [20] highlighted the stratigraphic significance of the Baluti shale and associated Carnian “Marker Dolomite.” Accordingly, the present microfacies results indicate a more restricted, argillaceous, and siliciclastic-influenced depositional system for the Baluti Formation compared with the more carbonate-dominated Kurra Chine succession.

5.3 Diagenetic Evolution and Porosity Development

Both the Kurra Chine and Baluti formations experienced complex marine, meteoric, and burial diagenesis, with dolomitization being the dominant alteration process. The occurrence of fine- to medium-crystalline dolomite within restricted lagoonal facies suggests early replacement by Mg-rich hypersaline fluids, followed by recrystallization during burial [4];[18]. The preservation of depositional fabrics in partially dolomitized samples indicates that dolomitization occurred through multiple stages, with the original depositional texture and degree of restriction influencing its distribution and intensity. Dissolution represents an important porosity-enhancing process, producing vuggy, moldic, and intercrystalline pores through post-depositional fluid circulation. This relationship between dolomitization, dissolution, and intercrystalline porosity is consistent with previous investigations of the Kurra Chine Formation [^]. In contrast, calcite cementation reduced pore connectivity by filling fractures, dissolution cavities, and other available pore spaces. Aswad et al. [23] similarly demonstrated that calcite cement contributed significantly to porosity reduction in the Kurra Chine Formation of the Sirwan Valley.

Petrophysical investigations further indicate substantial vertical and lateral variations in porosity and reservoir quality within the Kurra Chine Formation, emphasizing the combined influence of depositional facies and subsequent diagenetic processes [9]. Palynofacies evidence also supports variations in depositional conditions rather than deposition under a single uniform marine environment [24]. In the Baluti Formation, the association of dolomitization, recrystallization, cementation, and secondary pore development similarly indicates a complex diagenetic history. The lithological and microfacies variability documented by [21] and [22] provides a depositional framework for interpreting this diagenetic heterogeneity. Overall, reservoir quality in both formations reflects the balance between porosity-enhancing processes, particularly dolomitization and dissolution, and porosity-reducing processes such as cementation and compaction.

6. Comparison with previous studies

The petrographic and microfacies characteristics identified in the Baluti and Kurra Chine formations are broadly consistent with previous investigations of the Upper Triassic carbonate successions in northern Iraq. Early studies interpreted the Kurra Chine Formation as a shallow-marine carbonate platform affected by repeated transgression, restriction, and

regression [5-6]. More recent studies recognized restricted lagoon, open-lagoon, shoal, tidal-flat, and supratidal microfacies, supporting deposition on a homoclinal carbonate ramp influenced by relative sea-level fluctuations [7-8]. The present study supports these interpretations but indicates that the Sirwan and Ranya sections were dominated by restricted inner-ramp conditions, with episodic development of open-lagoon and shoal-margin environments. The observed facies distribution reflects variations in accommodation space, hydrodynamic energy, and marine circulation. The results also emphasize the important role of diagenesis, particularly dolomitization, dissolution, cementation, recrystallization, and compaction, in modifying carbonate fabrics and controlling pore-system evolution. These observations are consistent with [^], who emphasized the influence of sedimentological and diagenetic heterogeneity on the reservoir properties of the Kurra Chine Formation.

For the Baluti Formation, the present results agree with [21], who recognized restricted lagoonal, tidal-flat, subtidal, and shoal environments. The occurrence of dolomitic mudstone, argillaceous dolomudstone, dolomitic siltstone, and peloidal–bioclastic facies in the present study supports a predominantly restricted inner-ramp setting, interrupted by episodes of increased marine circulation and depositional energy. The lithological heterogeneity reported by [22] further supports the interpretation of Baluti as a heterogeneous shallow-marine succession. Diagenetic processes also exerted an important control on reservoir heterogeneity. Balaky et al. [8] demonstrated that dolomitization and dissolution may enhance pore development, whereas cementation, compaction, and recrystallization may reduce pore volume and permeability. Calcite cementation was also shown to influence porosity evolution in the Sirwan Valley [23], while substantial variations in petrophysical properties were documented within the Kurra Chine Formation of the Sarta Oil Field [9]. These observations are consistent with the present petrographic results, which demonstrate that the interaction between depositional facies and subsequent diagenetic processes controlled the development and destruction of pore spaces. Compared with previous investigations, the present study integrates petrographic observations, standard microfacies classification (SMF), Wilson’s Facies Zones (FZ), depositional-environment reconstruction, and diagenetic interpretation. The comparison of the Sirwan and Ranya sections further provides evidence for lateral facies variability and spatial changes in the Upper Triassic carbonate system along the northeastern margin of the Arabian Plate. Overall, the studied succession represents a heterogeneous shallow carbonate-ramp system rather than a uniform carbonate platform. The Kurra Chine Formation is dominated by restricted inner-ramp conditions with episodic open-lagoon and shoal-margin

development, whereas the Baluti Formation records more restricted conditions with stronger argillaceous and siliciclastic influence. Subsequent dolomitization, dissolution, cementation, recrystallization, and compaction further modified the original fabrics and controlled the final pore-system characteristics of the Upper Triassic succession.

7. Conclusions

Petrographic and microfacies analyses indicate that the Kurra Chine and Baluti formations were deposited within shallow homoclinal carbonate ramps along the northeastern Arabian Plate during the Late Triassic. Four carbonate microfacies were recognized in Kurra Chine Formation and six microfacies for Baluti Formation, that representing depositional environments ranging from restricted lagoon to open lagoon and shoal-margin settings. The Kurra Chine Formation records relatively more open marine conditions, whereas the Baluti Formation reflects a more restricted depositional system influenced by intermittent siliciclastic input. Dolomitization was the dominant diagenetic process in both formations, modifying the original carbonate fabrics and generating secondary intercrystalline porosity. Dissolution locally enhanced porosity, whereas calcite cementation, recrystallization, and compaction reduced pore connectivity. The integration of petrography, microfacies analysis, and diagenetic interpretation provides a comprehensive depositional and diagenetic model for the Upper Triassic carbonate successions of northern Iraq and The comparative investigation demonstrates that the Kurra Chine Formation records relatively greater marine connectivity than the Baluti Formation, whereas both formations experienced similar diagenetic evolution dominated by dolomitization and dissolution.

8. References

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