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# Sedimentological Study of the Balambo Formation (lower Cretaceous) in the Exposed Part of the Selected Section from Choman Area, Erbil, Iraqi Kurdistan Region

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## ABSTRACT

A detailed sedimentology of the Balambo Formation (Lower Cretaceous), including petrography, mineralogy, microfacies analysis, and depositional environment, has been conducted in the Razan section, Northeastern Iraq. The formation is comprised of alternation of thin to medium, yellowish grey and grey marly limestone, medium bedded limestone, thin bedded dark grey to black shales, thin bedded grey to green marl with dark bands and nodules of chert. Based on the petrographic investigation, the main skeletal grains in the carbonate of the Balambo Formation include planktonic foraminifera, calcispheres, and radiolaria. The major diagenetic processes affecting the carbonate of the formation include micritization, neomorphism, dolomitization, cementation, compaction, dissolution, and pyritization. Some marl and shale samples are subjected to X-ray diffraction investigation, which revealed that the non-clay minerals are pyrite, dolomite, quartz, and calcite, while the clay minerals are kaolinite and illite. To ascertain and interpret the depositional environment of the formation, three primary microfacies are identified in the carbonate of the Balambo Formation and then subdivided into six submicrofacies. Petrographic examination and microfacies research show that a basinal, deep-water environment is where the Balambo Formation in the Razan section was deposited.

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# دراسة رسوبية للاجزاء المنكشفة من تكوين بالمبو (الكريتاسي الاسفل) لمقطع سطحي في منطقة جومان، اربيل، اقليم كوردستان العراق

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**الملخص**

تمت الدراسة الرسوبية التفصيلية والتي تتضمن البتروغرافية والمعدنية والتحليل السحني والبيئة الترسيبية لتكوين بالمبو في مقطع رازان شمال شرقي العراق. يتألف التكوين من تعاقب الحجر الجيري المارلي بلون رمادي الى رمادي مصفر وبطبقات نحيفة الى متوسطة التطبق مع حجر جيري متوسط التطبق مع السجيل الاسود اللون نحيف التطبق مع المارل الرمادي الى الاخضر اللون مع عقد او طبقات من الجيرت الاسود اللون. اعتمادا على الدراسة البتروغرافية، فان اهم المكونات الهيكلية في الصخور الجيرية لتكوين بالمبو تشمل الفورامنيفيرا الطافية والكرات الكلسية والراديولاريا. وان اهم العمليات التحويرية المؤثرة على صخور التكوين هي المكرتة والتشكل الجديد والدلمتة والسمنتة والانضغاط والاذابة وعملية تكون البايرايت. يظهر من دراسة حيود الاشعة السينية لنماذج مختارة من المارل والسجيل ان المعادن غير الطينية هي الكالسايت والكوارتز والدولومايت والبايرايت، فيما تتالف المعادن الطينية من الالايت والكاؤولينايت. الانواع الثلاثة الرئيسة من السحنات الدقيقة وصفت في الصخور الجيرية للتكوين والتي قسمت بدورها الى ست سحنات ثانوية لتفسير البيئة الترسيبية للتكوين. تدلل الدراسة البتروغرافية والتحليل السحني الدقيق على ترسيب التكوين في مقطع رازان ببيئة حوضية عميقة.

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## Introduction

The Balambo Formation is one of the Cretaceous formations with a widespread distribution across northeastern Iraq. In the type locality area, the Balambo Formation was deposited across nearly the entire Cretaceous period (Jassim and Goff, 2006). In the High Folded and Imbricated Zones of Iraq, the Balambo Formation is widely distributed (Buday, 1980). Wetzel (1947) initially described it in Bellen et al. (1959) from the Sirwan Valley, which is located 10 km southeast of the city of Halabja in northeastern Iraq.

The thickness of the formation varies from place to another, and at the type locality, it is about 315 m thick (Bellen *et al.*, 1959). The formation can be divided into two units of Valanginian-Middle Albian and Late Albian-Turonian ages, representing the lower and upper Balambo Formation, respectively (Buday, 1980). The thickness of the formation at the studied section is about 210 m, and the lower part of the formation is not exposed but covered by a recent deposit. In the selected section, the formation is comprised of alternation between thin, yellowish grey and grey marly limestone, medium to thick bedded limestone, thin bedded dark grey to black shales, thin bedded grey to green marl with bands and nodules of chert. According to Buday (1980), the Balambo Formation is an equivalent of the Sarvak Formation of the east Zagros Mountain in Iran. Since that time, there are several works have been conducted on the

Balambo Formation. These include the works of (Al-Haba and Abdullah, 1989; Al-Dulaimi and Mahdi, 2008; Abawi and Hammoudi, 2008; Daoud et al., 2010; Ahmed et al., 2015; Karim et al., 2016; Sagular and Algburi, 2018; Al-Mutawali and Al-Khafaf, 2018; Al-Khafaf and Al-Mutawali, 2019; Al-Miamary, 2020; Al-Miamary et al, 2020; Sarraj and Mohialdeen, 2020; and Abdullah and Balaky, 2022).

By examining the sedimentology of the Balambo Formation in the chosen section in terms of petrography, mineralogy, and microfacies analysis, the study aims to ascertain the depositional environment of the Balambo Formation in the northeastern Iraqi Imbricated Zone.

## Geologic Setting

Iraq's Mesozoic strata were deposited in the Arabian craton's northeastern passive margin (Numan, 2000). The Balambo Formation is abundantly exposed along the core and limbs of various anticlines of the High Folded and Imbrication Zones (Bellen *et al.,* 1959). Numerous thrust-folded formations that run from the northwest to the southeast define the Imbricated Zone in northeastern Iraq (Jassim and Goff, 2006).

The studied outcrop of the Balambo Formation is chosen in the Imbrication Zone near Razan village. the selected section lies on the Hamlton road at Balak Valley approximately 10 km west of Choman City, Erbil Governorate, with coordinations (Latitude 44˚47′ 10″E and Longitude 36˚ 35' 23" N) (Fig. 1). The Balambo Formation from Razan section exposed at the northeastern limb of Spi-Balies anticline, it is asymmetrical anticline has a fold axis of NW-SE trend, and situated between Zagros main thrust in the NE and Zozik anticline in the SW (Balaki, 2004) (Fig. 2). The anticline is double plunging, and the length is around 26 km; and the southwestern limb of anticline is steeper and shorter than the northeastern limb, and commonly is overturned. This anticline exposes the Jurassic rocks formed in the core of the anticline, represented by the Sarki and Sehkaniyan formations. While Cretaceous rocks formed from the limbs of the anticline represent the Balambo and Qamchuqa formations. In the studied section, the Chia Gara Formation underlies the Balambo Formation. The contact is covered by the recent deposits. The Balambo Formation is overlaid by the Qamchuqa Formation, whose contacts are conformable and gradational (Fig. 3).

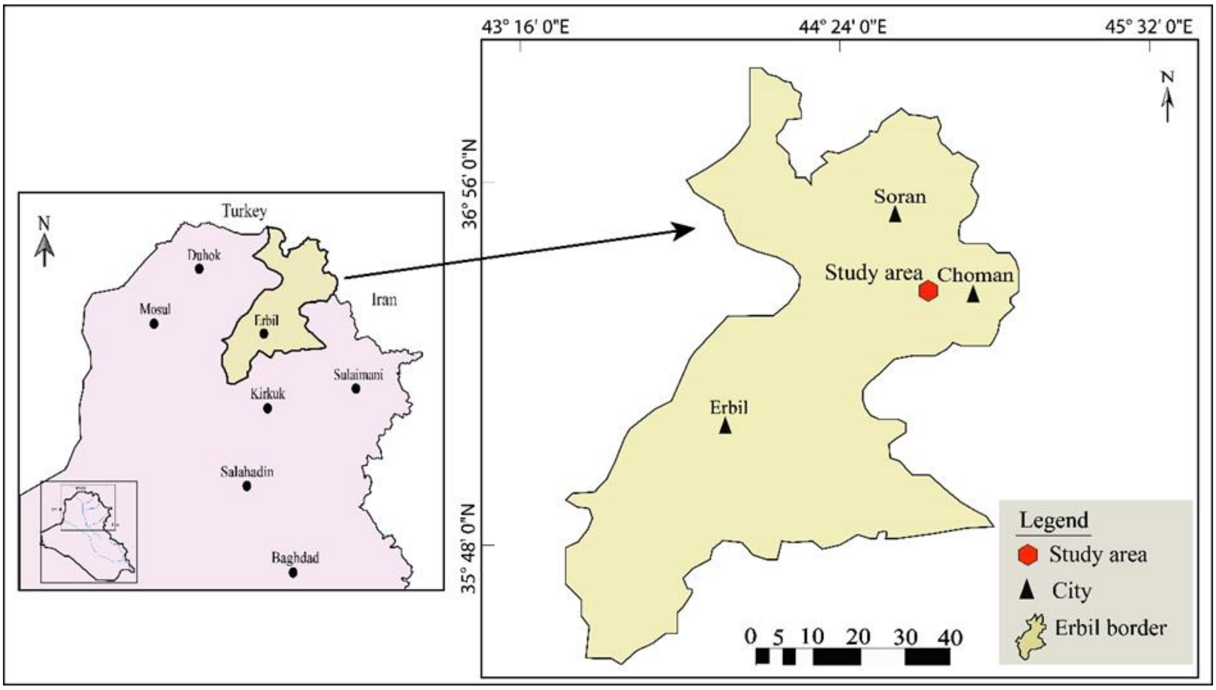


**Fig. 1. Location map of the study area.**

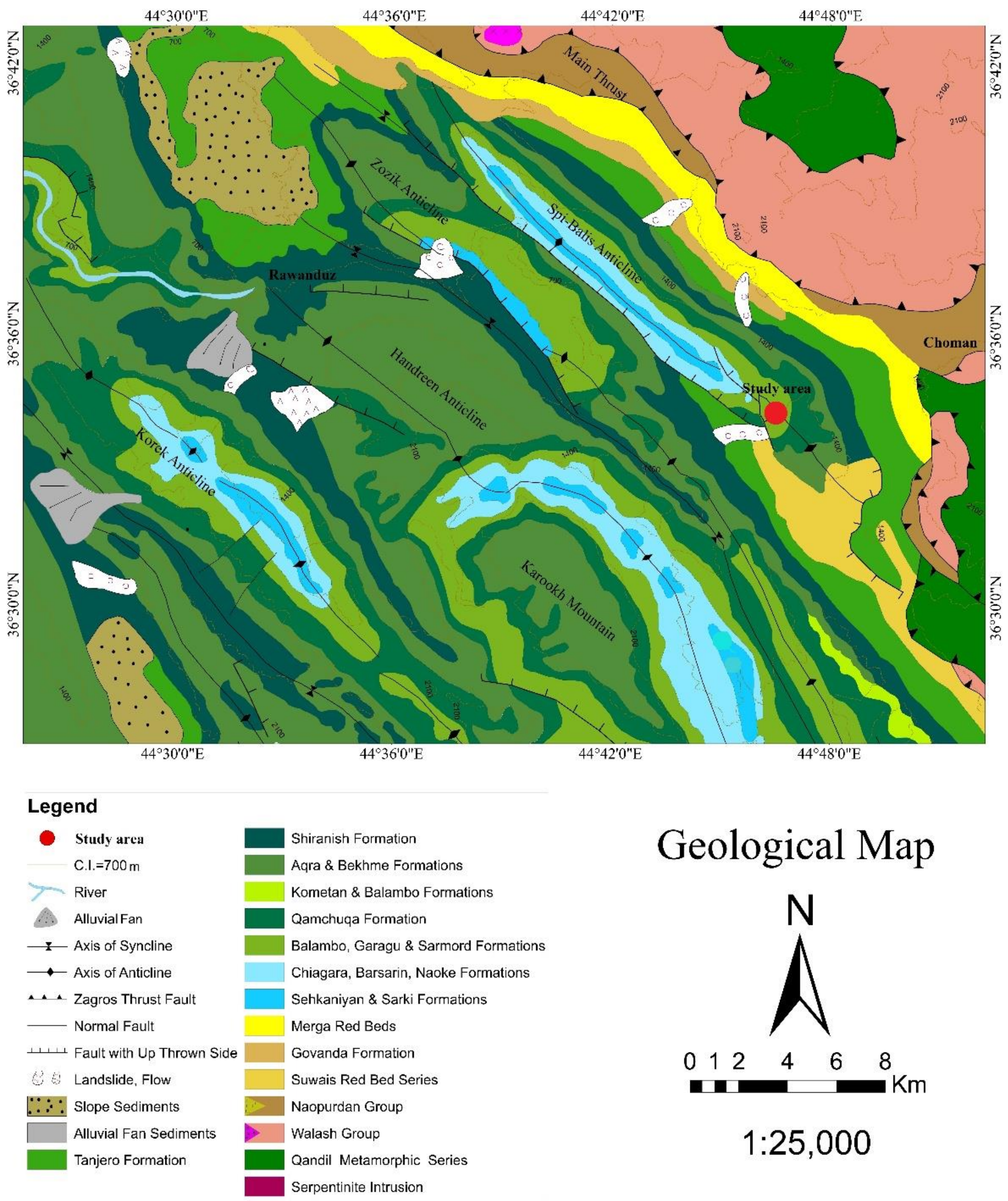


**Fig. 2. Geological map of the study area (after Delizy and Shingaly, 2022).**

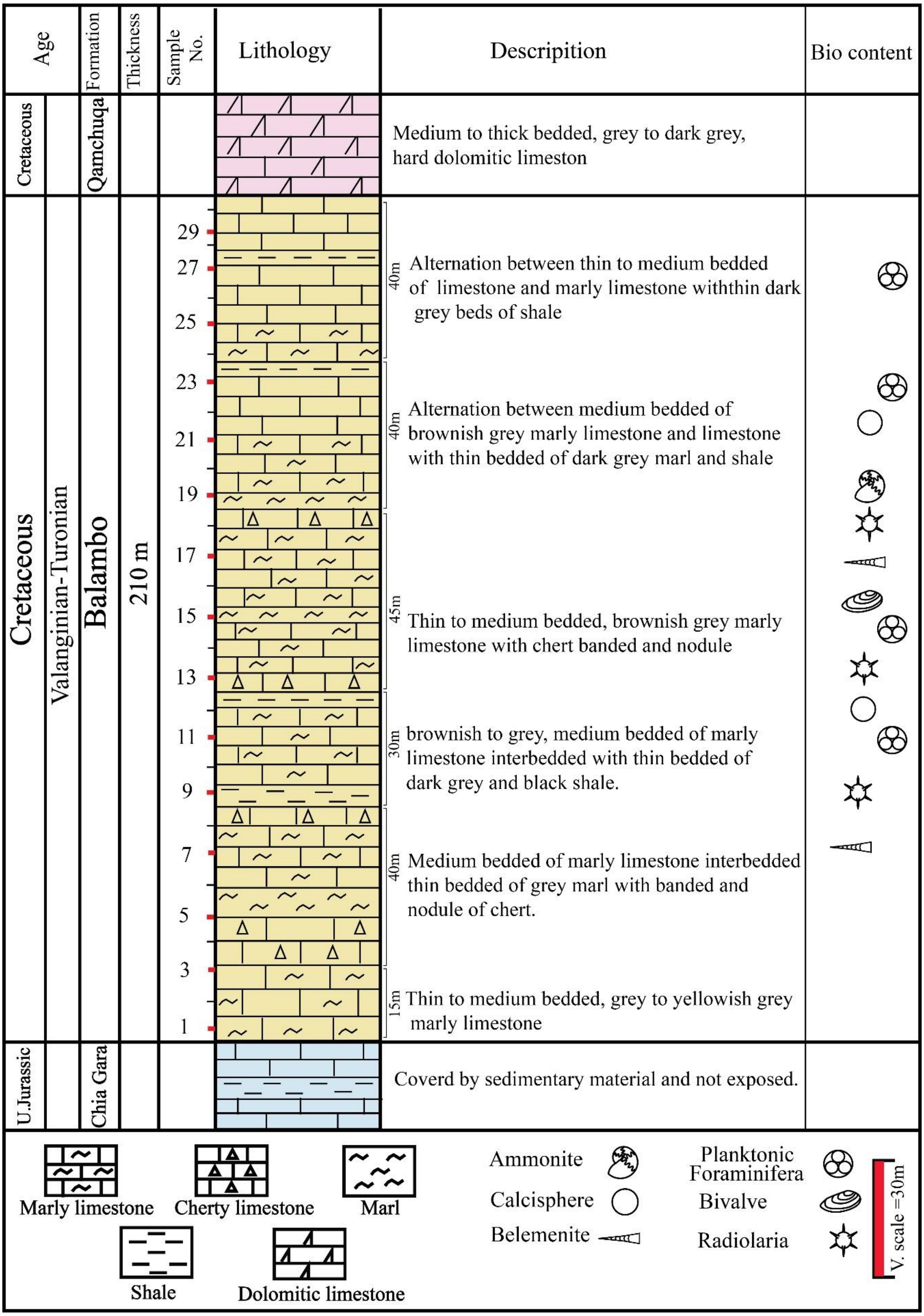


**Fig. 3. Stratigraphic column of the Balambo Formation, Razan section, northeastern Iraq.**

## Materials and Methods

To identify the appropriate part for the current investigation, a field trip was conducted in the Imbrication Zone. The NE limb of the Spi Balies anticline in the Imbricated Zone is selected as the Razan section. A detailed description and measurements of the lithology, grain size, and mineralogy of the formation are made. A total of 29 samples were taken from the section under study, and to ascertain and verify the nature of the boundary, additional samples from the upper contact with the Qamchuqa Formation were also collected. The Soran Research Center at Soran University prepared all thirty thin sections in accordance with Friedman's (1959) procedure to differentiate between calcite and dolomite. For the determination of the microfacies types of the formation, Dunham′s (1962) classification scheme is used. Furthermore, four marl and shale samples were analyzed by X-ray diffraction (XRD) to determine their clay and non-clay mineral content; the XRD technique was conducted in the laboratories of Soran Research Center, Soran University.

## Results and Discussion

### Stratigraphy

The Late Valanginian-Turonian Balambo Formation in the studied area is 210 meters thick (Figs. 3 and 4a). The lower part of the formation is nearly 55 m thick, and comprises intercalation of thin-medium bedded, dark-grey to yellowish-grey, soft shales and marls interbedded by thin-medium bedded, pelagic, fine-grained, light-grey marly limestones (Fig. 4b). Very limited fossils are recorded from the surface of the beds, including belemnites, ammonites, and poorly preserved bivalves. Bands and nodules of black chert are also recorded between beds of the marly limestones, and yellowish pyrite nodules are also recorded (Fig. 4c, d). Concerning the source of silica for the chert nodules in limestone and marly limestone, it is believed to be the dissolution of siliceous organisms such as radiolarian, sponge spicules, and possible upwelling currents (Blatt *et al.,* 1980).

Stylolites are observed in the surface of the marly limestone layers (Fig. 4e). The middle part (mixed carbonate and clastic unit) is approximately 75 m thick and consists of well-bedded, fine-grained, dark-grey, organic, pelagic marly limestones interbedded with well-bedded, dark-grey to yellowish-grey, soft shales and marls (Fig. 5a, b). The middle part of the formation in the studied section contains diverse macro and micro-fossils. Nodules and lenses of black, fractured chert are found in this part. The upper part of the Balambo Formation in the studied section is about 80 meters thick and consists of thin layers of dark grey shales interbedded with stacked, medium-to thin-bedded, dark-grey, fine-grained, slightly marly limestones and limestones (Fig. 5c). The layers of this part sometimes appear in wavy lamination (Fig. 5d). The fossils recorded in this part include well-preserved ammonites, belemnites, bivalves, radiolarians, calcispheres, and planktonic foraminifers (Fig. 5e).

The Balambo Formation underlies the Qamchuqa Formation, and the nature of the contact is conformable and gradational, taken at the top of the well-bedded, black, pelagic limestones of the Balambo Formation and base of thick-bedded, greyish, dolomitized limestones and dolomites of the Qamchuqa Formation (Fig. 5f). The Chia Gara Formation lies beneath the Balambo Formation, which is covered by sedimentary deposits.

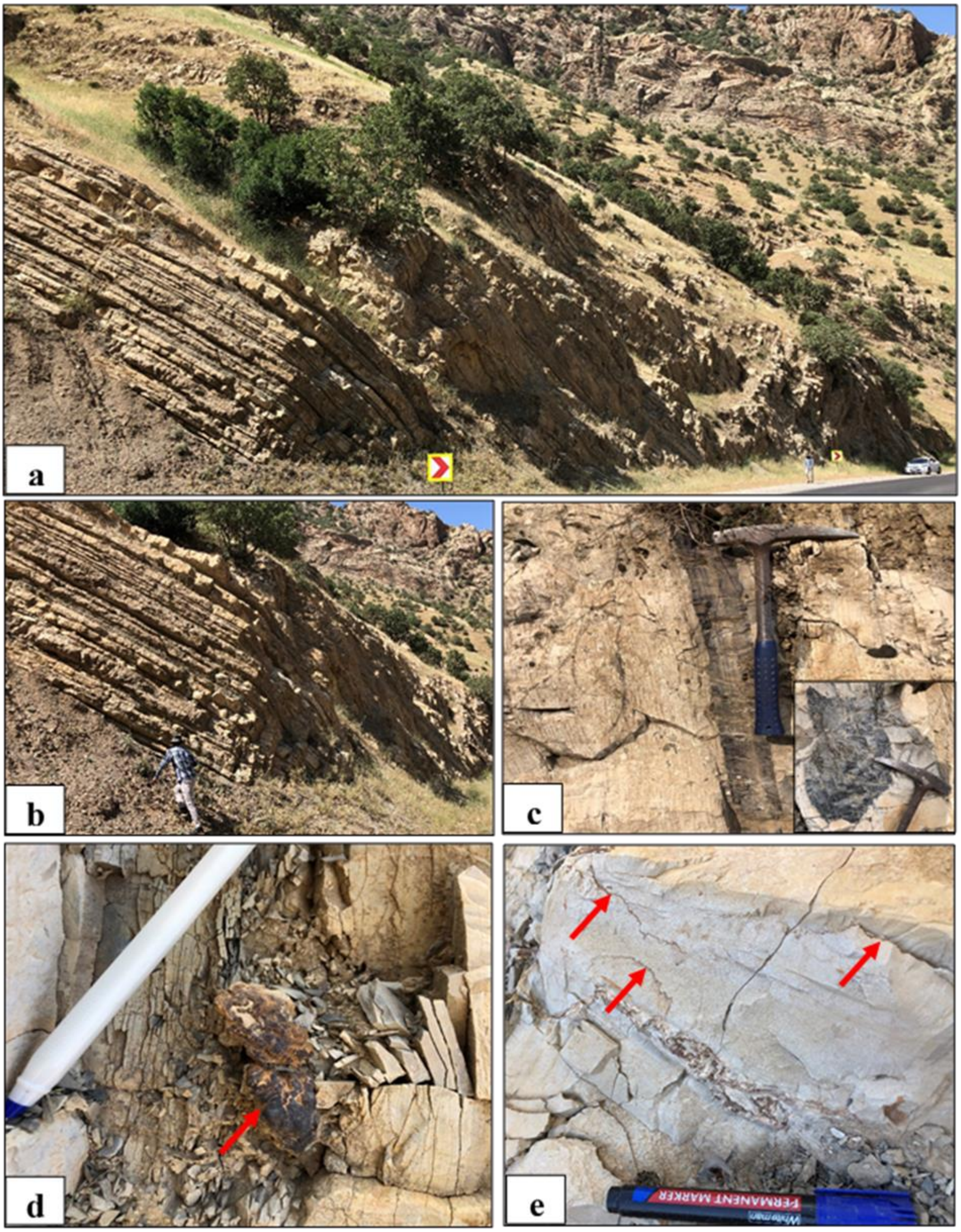


**Fig. 4. Field photographs showing: a) The Cretaceous successions of the Razan section, including the Balambo Formation. b) Lower part of Balambo Formation, which consists of marly limestone interbedded within beds of marl and shale. c) Bands and nodules of chert from the lower part of the formation. d) Nodule of pyrite within marly limestone of the formation (red arrow). e) Suture of stylolites is observed from the surface of beds in the lower part of the formation (red arrows).**

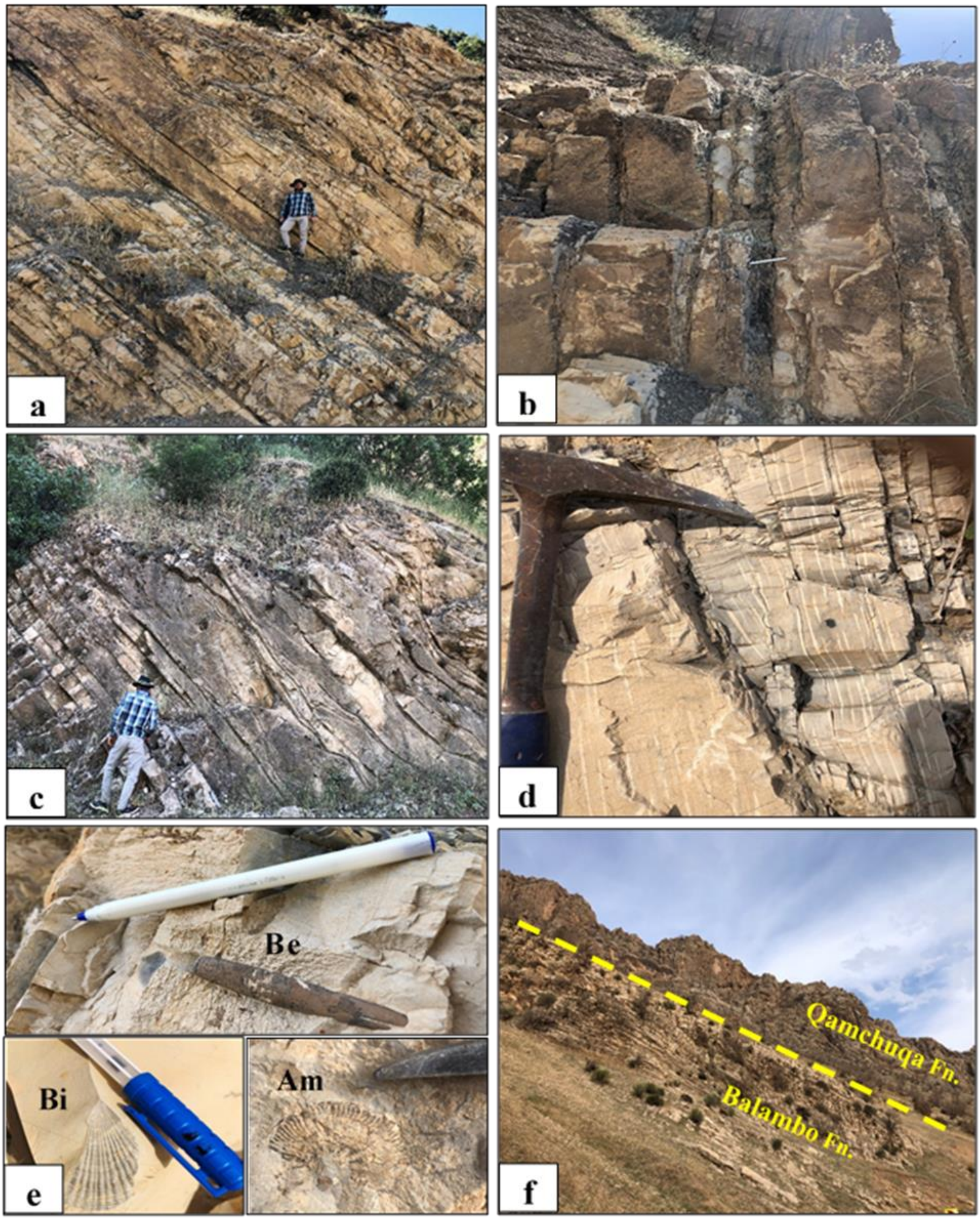


**Fig. 5. Field photographs showing: a) The middle part of the Balambo Formation in the Razan section. b) Layers of marl and shale intercalation with medium to thick beds of marly limestone. c) Upper part of the Balambo Formation comprised of marly limestone, limestone, and thin-bedded shale. d) thin laminae (calcic laminae) from beds of the formation in the upper part. e) Macrofossils appear from beds of the Balambo Formation, which includes Belemnite (Be), Bivalve (Bi), and Ammonite (Am). f) Upper contact of the Balambo Formation with overlaid Qamchuqa Formation in the Razan section.**

## Petrography and Diagenesis

Several petrographic components are revealed by the petrographic analysis of thirty thin sections of the Balambo Formation. The main groundmass is micrite, while the main skeletal grains include different kinds of fossils such as: planktonic foraminifera (*Globigerinelloids* (Fig. 6a), *Ticinella primula* (Fig. 6b), *Vitorfus morine* (Fig. 6c), *Archaeodictyomitra* (Fig. 6c), *cryptamphorella conara* (Fig. 6d), and *Planohetrohelix globulosa* (Fig.6e), radiolarian (*Crucella messinae*) (Figs. 6f and 7a), and calcispheres (Fig. 7a, b).

Numerous diagenetic processes have impacted the carbonate rock strata in specific regions of the Balambo Formation. The primary diagenetic processes observed in the thin sections under study are pyritization, micritization, neomorphism, dolomitization, cementation, dissolution, and compaction. Micritization is the main and most important early diagenetic process affecting the carbonates of the Balambo Formation, which are recorded as a micritic rim around skeletal grains (micritic envelope) (Fig. 6b).

Neomorphism has a significant impact on the micritic matrix in the thin sections under study (Fig. 7c), and it also has an impact on the majority of the skeletal grains.

Another diagenetic process is dolomitization, which occurs only in early phases, and most of the rhombs of dolomite are detected in the micritic groundmass. The extremely fine dolomite crystals that are typical in the various areas of the section under study are indicative of the early dolomitization (Fig. 7d). Cementation is a diagenetic process that also exists in the carbonate of the Balambo Formation. Three primary forms of cement are identified: blocky cement (Fig. 7e), drusy cement (Fig. 7f), and granular cement (Fig. 8a). Different types of cement reflect variation in the diagenetic environment. Granular cement is formed in the vadose zone (marine and meteoric), while drusy cement is formed in the vadose and phreatic zone, and blocky cement is formed under meteoric (phreatic and vadose) water (Flügel, 2010). There are different forms of porosity, such as moldic (Fig. 8b), fracture (Fig. 8c), vuggy (Fig. 8d), and also dissolution. Compaction comes in both mechanical and chemical forms, but in the section under study, only the chemical type represented by stylolites is seen (Fig. 8e).

In addition, pyritization is recorded in the present study, which results in several crystal forms of pyrite that were precipitated within the marl and marly limestone of the Balambo Formation, and formed under reducing conditions (Berner, 1984; Rasool *et al.*, 2024) (Fig. 8d).

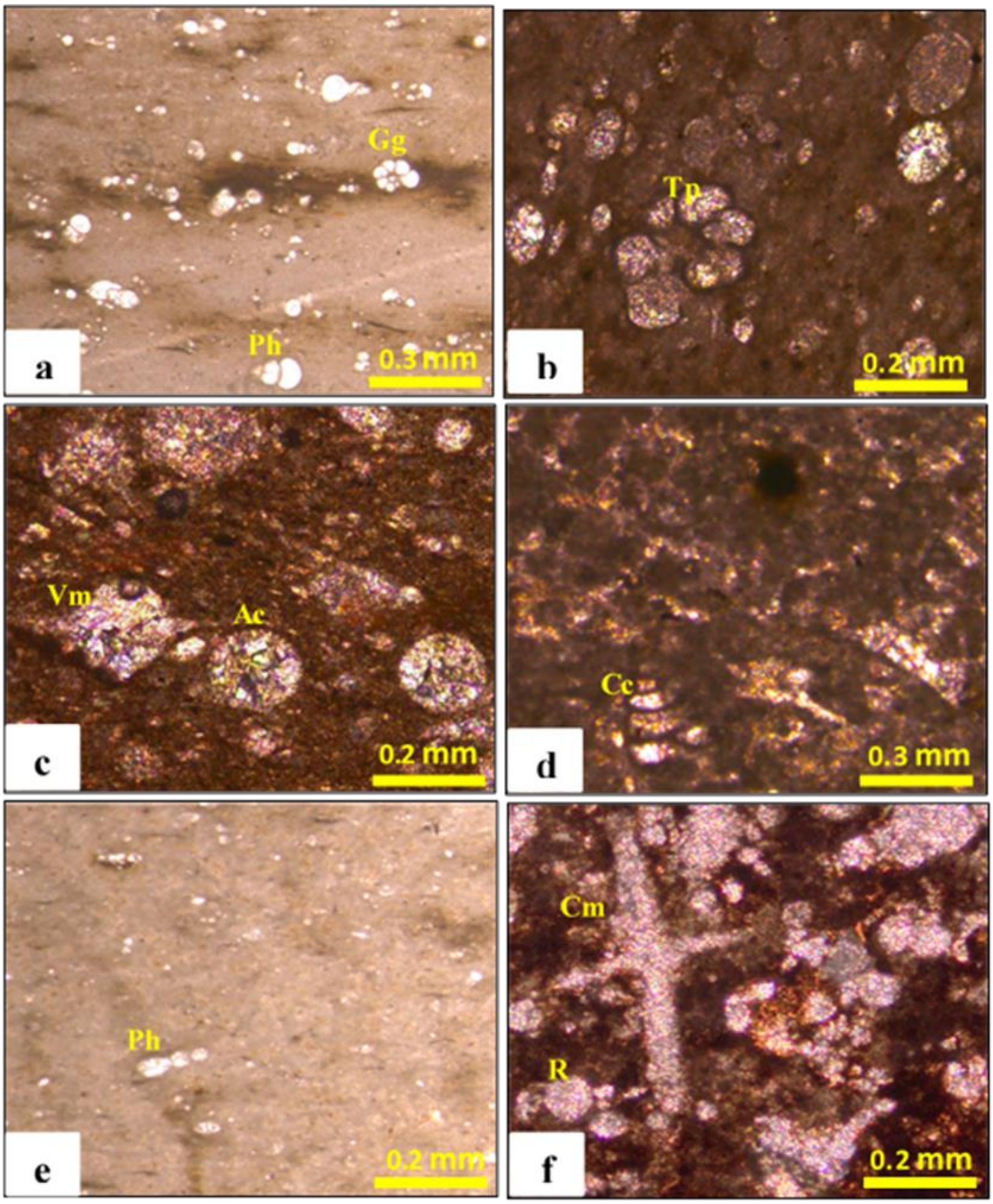


**Fig. 6. Thin section photomicrographs of the Balambo Formation: a) Planktonic foraminifera including *Globigerinelloids* (Gg), *Planohetrohelix* (Ph). BR11. P.P. b) Planktonic foraminifera, including *Ticinella primula* (Tp) within micrite groundmass and affected by micritization. BR15. X.N. c) Planktonic foraminifera, including *Vitorfus morine* (Vm), *Archaeodictyomitra* (Ac), and some fossils affected by neomorphism. BR22. X.N. d) Planktonic foraminifera, including *cryptamphorella conara* (Cc) in micrite groundmass. BR22. X.N. e) Planktonic foraminifera lime mudstone including *Planohetrohelix globulosa* (Ph). BR11. P.P. f) Calcitized radiolarian skeletal grains including *Crucella messinae* (Cm). BR9. X.N.**

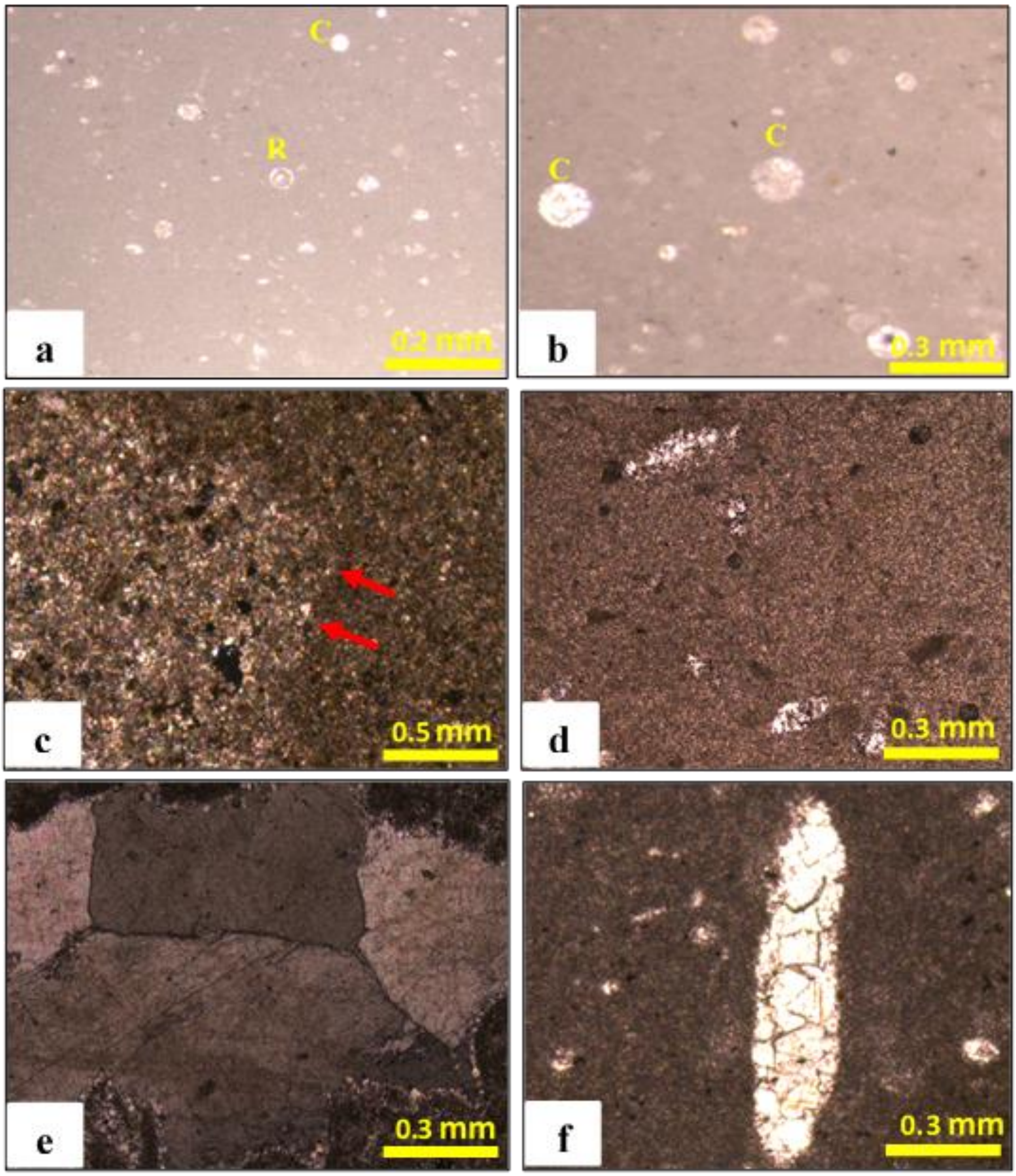


**Fig. 7. Thin section photomicrographs of the Balambo Formation: a) Calcitized radiolarian and calcispheres grains within micritic groundmass. BR12. P.P. b) Calcispheres grains within neomorphosed micritic matrix. BR12. P.P. c) Neomorphism of micrite to microspar and pseudospar (Red arrow). BR3. P.P. d) Fine dolomite crystal representing an early stage of dolomitization. BR10. P.P. e) Blocky cement filling the fracture (vein). BR16. P.P. f) Drusy cement filling bioclast BR16. P.P.**

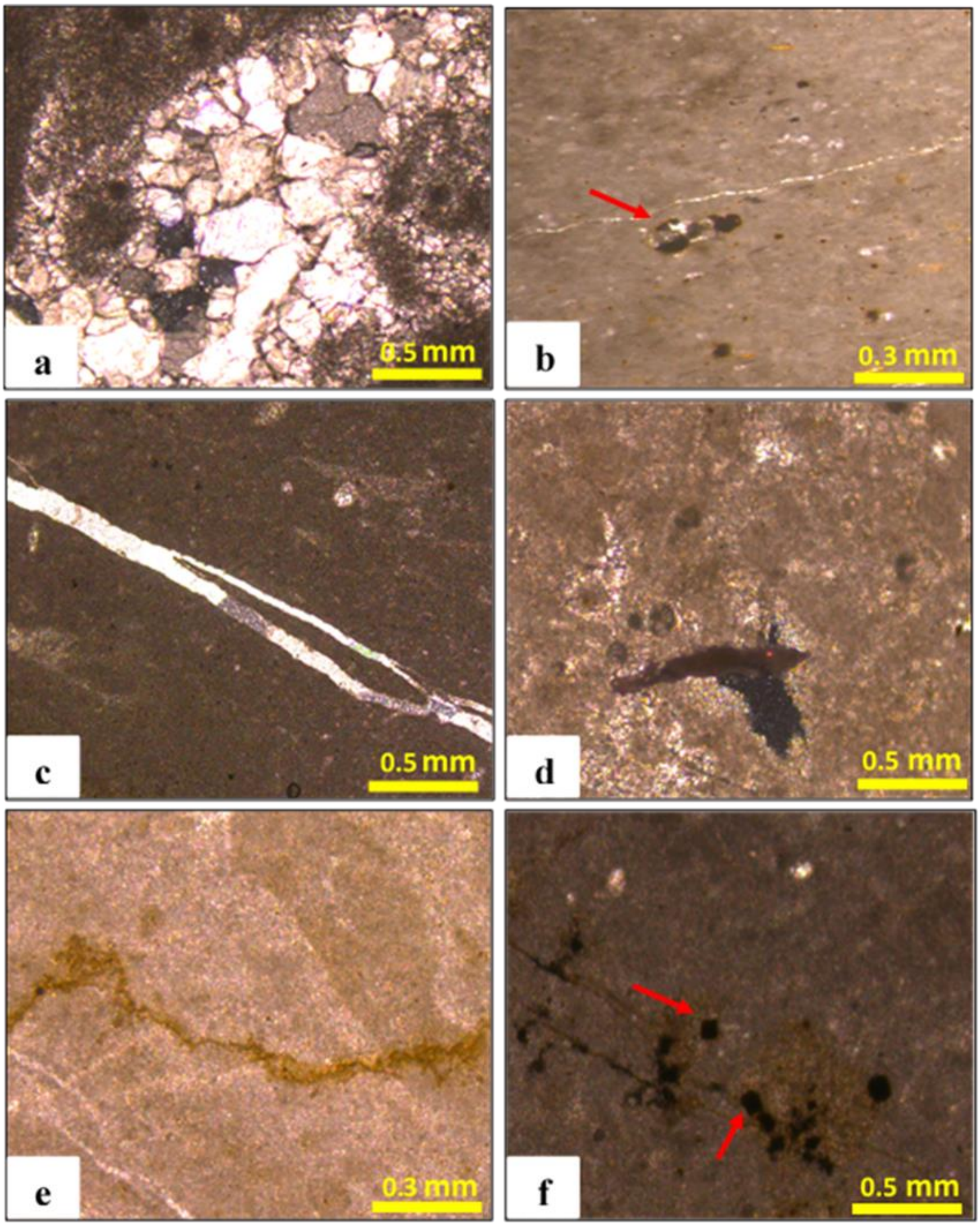


**Fig. 8. Thin section photomicrographs of the Balambo Formation: a) Granular cement type partly filling a vein BR22. P.P. b) Moldic porosity of planktonic foraminifera, partly filled by organic matter (Red arrow). BR11. P.P. c) Fracture porosity type, reduced fracture by cementation. BR5. X.N. d) Vuggy porosity in micritic matrix groundmass. BR26. P.P. e) Sutured stylolite, irregular with peaks of low amplitude BR23. P.P. f) Small cubic pyrite in neomorphosed micritic matrix (Red arrows). BR6. X.N.**

## Mineralogy

Figure 9 displays the mineralogical composition of the XRD analysis. The main components of non-clay minerals are calcite, dolomite, quartz, and pyrite. The most prevalent non-clay mineral in the samples under study is calcite, which is consistent with the widespread occurrence of calcareous fossils like planktonic foraminifera. On the other hand, kaolinite and illite predominate clay minerals. Illite is found in shale and marl, suggesting that the northeastern region of Iraq had experienced a hot, dry climate during the Aptian-Cenomanian period (Abdullah and Balaky, 2022).

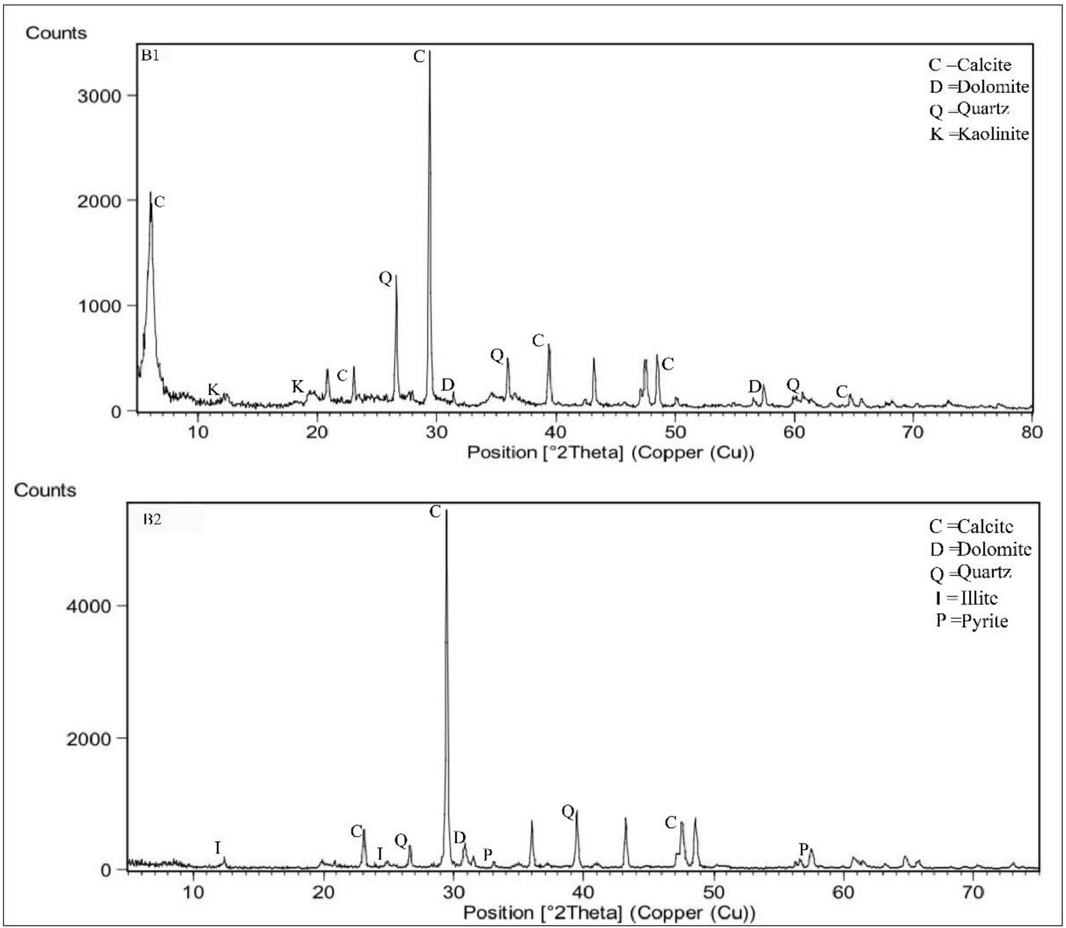


**Fig. 9. X-Ray diffractograms of selected samples of the Balambo Formation at the Razan section.**

## Microfacies

The Balambo Formation comprises different lithologies such as marly limestone, marl, shale, and chert. the different types of microfacies in carbonate of the Balambo Formation are defined and classified according to Dunham's (1962) classification. The main microfacies are the lime mudstone, lime wackestone, and lime packstone microfacies. Several submicrofacies are determined based on the components of the main microfacies. Each of the defined submicrofacies is compared with Wilson (1975) Facies zones (FZ) and Standard Microfacies (SMF) of Flügel (2010) to determine the depositional setting of the Balambo Formation (Table 1).

***Lime mudstone microfacies***

This microfacies, which ranks second in importance in the studied section after the wackestone microfacies, is characterized by a high micrite (mud-supported) content. The skeletal grains of this microfacies are less than 10 %; it includes planktonic foraminifera (*Globigerinelloides*, *Planohetrohelix globulosa*), radiolarian, and calcispheres. It is abundant in different parts of the formation, especially in the middle part of the formation. The main diagenetic processes in these facies are dolomitization and neomorphism. This microfacies is subdivided into planktonic foraminifera lime mudstone (M1) (Figs. 6e and 10a) and radiolarian-calcispheres lime mudstone submicrofacies (M2) (Figs. 6e and 10b).

***Lime wackestone microfacies***

This microfacies is the most common in the studied section, which is composed of micritic matrix involving skeletal grains ranging between 10-40 %. The main skeletal components in this microfacies are planktonic foraminifera (*Globigerinelloids*, *Ticinella primula,* and *Planohetrohelix globulosa*) and radiolaria. The most common diagenetic process affecting the carbonate of these microfices is micritization. Another diagenetic process is neomorphism. It includes the pelagic radiolarian lime wackestone (W1) (Fig.10c), Globigerinelloides lime wackestone (W2) (Fig. 10d), and planktonic foraminifera lime wackestone (W3) (Fig. 10e).

***Lime packstone microfacies***

Only the middle and upper regions of the Balambo Formation in the chosen section contain this microfacies. It is characterized by abundant grain content that ranges between 50-80 % embedded in micritic groundmass (Dunham, 1962). This microfacies includes radiolarian lime packstone (P), which forms the main submicrofacies (Fig. 10f) and is affected by micritization and neomorphism processes.

**Table 1: Main microfacies and subdivisions of the Balambo Formation in the studied section.**

| Main microfacies Dunham (1962) | Subdivision of Dunham (1962) | Diagenesis features + Type of grains | SMF (Flügel, 2010) | FZ (Wilson, 1975) |
|---|---|---|---|---|
| Lime Mudstone | Planktonic foraminifera lime mudstone (M1) | It is characterized by the presence of skeletal grains (*Globigerinelloides*, *Ticinella primula*), and it is affected by diagenetic processes such as micritization, dolomitization, and cementation. | SMF 3 | FZ 2 |
| | Radiolarian- Calcispheres lime mudstone (M2) | The main fossils are calcitized radiolarian and calcispheres within micritic groundmass. The major diagenetic features are micritization and cementation. | | FZ 1 |
| Lime Wackestone | Pelagic Radiolarian lime wackestone (W1) | The main skeletal grain in this submicrofacies is radiolarian in micritic groundmass. Micritization is the main diagenetic process. | | FZ 1 |
| | Globigerinelloides Lime wackestone (W2) | The planktonic foraminifera (*Globigerinelloides*) is the main skeletal grain and are affected by diagenetic processes such as micritization and neomorphism. | | FZ 2 |
| | Planktonic foraminifera lime wackestone (W3) | The main planktonic foraminifera are (*Globigerinelloids*, *Ticinella primula,* and *Planohetrohelix globulosa.* The main diagenetic features are micritization and dolomitization. | | FZ 2 |
| Lime Packstone | Radioarian lime packstone (P) | The primary skeletal grain in this submicrofacies is radiolarian, which is impacted by the micritization process and contains a rare quantity of micritic matrix. It is found in the middle and upper part of the formation. | | FZ 1 |

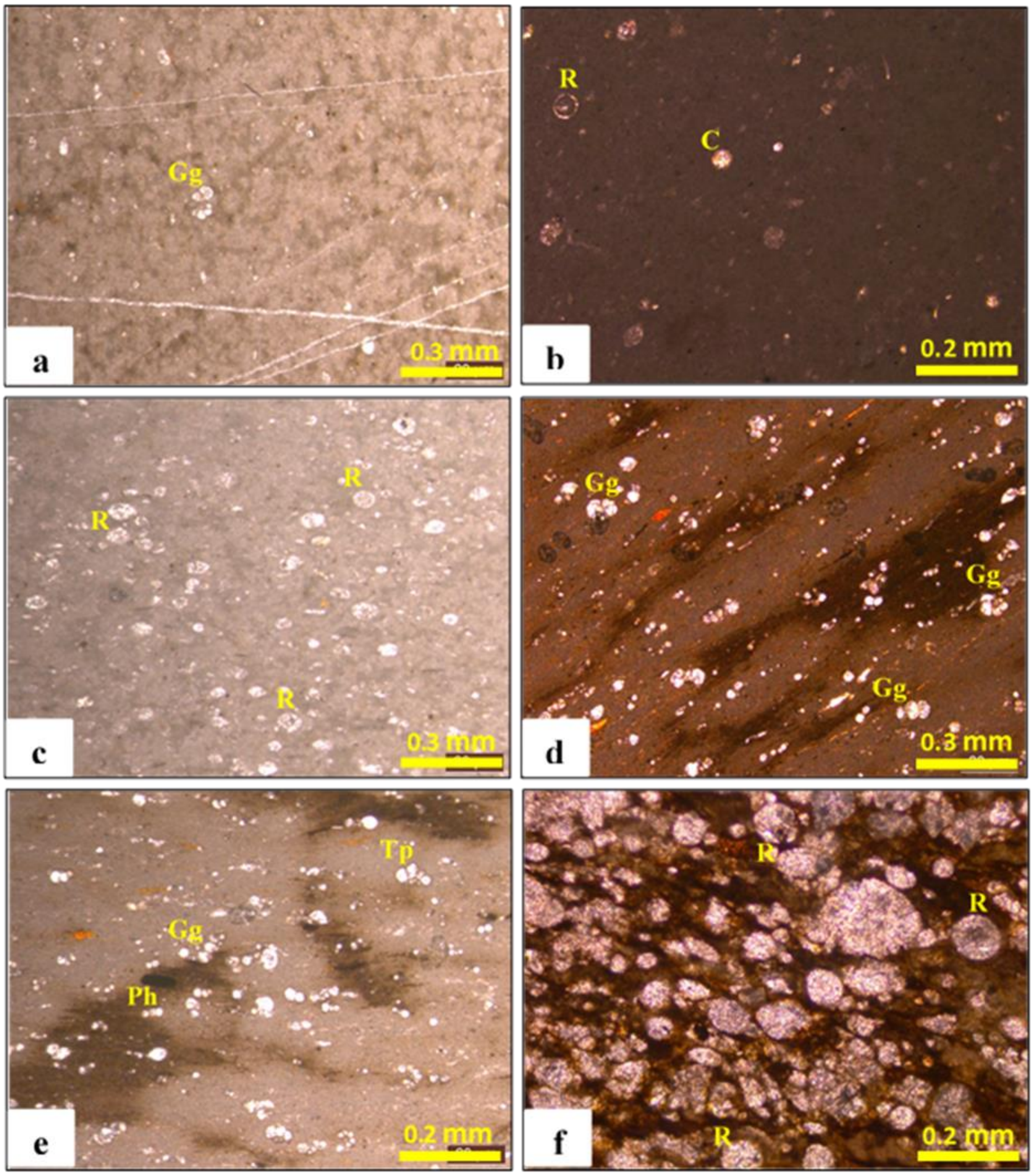


**Fig. 10. Thin section photomicrographs of the Balambo Formation: a) planktonic foraminifera lime mudstone submicrofacies, the main components are *Globigerinelloides* (Gg), *Planohetrohelix* (Ph). BR13. P.P. b) radiolarian-calcispheres lime mudstone submicrofacies. (Ph). BR8. P.P. c) Pelagic radiolarian lime wackestone, the main component is calcitized radiolarian. (Ph). BR12. P.P. d) Globigerinelloides lime wackestone, major component is *Globigerinelloides* (Gg) in micritic matrix. (Ph). BR27. P.P. e) planktonic foraminifera lime wackestone, main components *Globigerinelloids* (Gg), *Ticinella primula* (Tp), and *Planohetrohelix globulosa* (Ph). BR11. P.P. f) radiolarian lime packstone including caicitized radiolarian. (Ph). BR18. P.P.**

## Facies association

Based on the petrographic analysis and microfacies types in the carbonates of the Balambo Formation in the studied section, two main facies associations could be recognized, which are the basinal deep water and the deep shelf. The basinal deep water facies association is composed of mudstone, wackestone, and packstone microfacies, including skeletal components such as radiolaria and calcisphere. Micrite with a high content of organic matter affected by the neomorphism process dominates this facies association. The occurrence of radiolarian, calcispheres, and a high amount of dark color micrite matrix is an indicator for the deep basinal marine environment (Flügel, 2010). The basinal deep water facies corresponding to the FZ 1 and similar to the standard microfacies SMF 3 suggest that the deposition was in a basinal deep water environment. This facies association, which includes the Balambo Formation in the section under study, is made up lithologically of black shale with banded and nodular chert, thin-bedded grey marl, and yellowish grey medium-bedded limestone.

The deep shelf association is characterized by abundant calcispheres and planktonic foraminifera with minor radiolarians and bioclasts within mudstone and wackestone textures. According to Flügel (2010), the presence of abundant planktonic foraminifera in this association represents an upper bathyal deep shelf marine environment. The deep shelf facies corresponding to the FZ 2 and comparable to the standard microfacies SMF 3 suggest that the deposition was in a deep shelf environment.

Petrographically, both facies' associations include the main skeletal grains such as: planktonic foraminifera (*Globigerinelloids*, *Ticinella primula*, *Vitorfus morine*, *cryptamphorella conara*, *Archaeodictyomitra,* and *Planohetrohelix globulosa*), radiolarian, and calcispheres.

**Depositional Environment**

In this study, the depositional environment of the Balambo Formation is ascertained through the use of petrographic analysis, microfacies, and mineralogical composition. The presence of each petrographic component in the carbonates of the Balambo Formation suggests that the deposition was in basinal deep water and deep shelf conditions.

According to Flügel (2010), the deep-water marine setting is divided into basinal deep-water, deep shelf, and toe of slope environments. Based on the facies zone of Wilson (1975), and the standard microfacies of Flügel (2010), the Balambo Formation belongs to the facies zone (FZ 1, FZ 2) and (SMF 3), which are related to the basinal deep-sea water and deep shelf environment. The existence of radiolarian and calcisphere in different parts of the formation indicates a highly quiet deep marine environment (Sagular and Al-Gburi, 2018; Omer *et al.*, 2023; Al-Taee *et al.*, 2024; Sulaiman *et al.*, 2023, 2024; Delizy *et al.*, 2025). The types of microfacies containing a high quantity of dark color micritic matrix with organic matter enrichment and a rare amount of sparite promote deposition in the deep-sea setting. The deep shelf is supported by the common occurrence of calcisphere and different planktonic foraminifera assemblages within lime mudstone and lime wackestone microfacies, such as (*Globigerinelloids*, *Ticinella primula*, *Vitorfus morine*, *Archaeodictyomitra*, *cryptamphorella conara,* and *Planohetrohelix globulosa*).

According to the abovementioned results, the suggested depositional model of the studied Balambo Formation is illustrated in Figure 11.

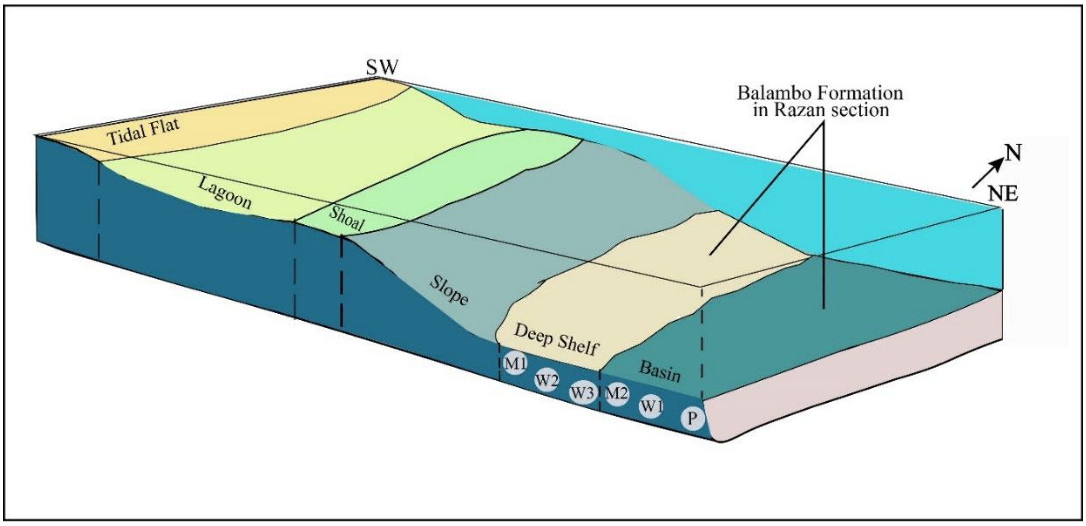


**Fig. 11. Depositional model of the Balambo Formation in the studied section.**

## Conclusions

1. Petrographically, the carbonate of the Balambo Formation in the selected section is composed of different skeletal constituents, including Planktonic foraminifera (*Globigerinelloids*, *Ticinella primula*, *Vitorfus morine*, *cryptamphorella conara*, *Archaeodictyomitra*, and *Planohetrohelix globulosa*), radiolarian, and calcispheres.
2. The main non-clay minerals in the shale and marl samples are calcite, quartz, dolomite, and pyrite, whereas the clay minerals are illite and kaolinite.
3. Different diagenetic processes have affected the carbonates of the Balambo Formation, including micritization, neomorphism, cementation, dolomitization, compaction, dissolution, and pyritization.
4. To interpret the depositional setting of the Balambo Formation, three microfacies subdivided into six sub-microfacies are found in the Balambo Formation.
5. The suggested depositional environment is the basinal deep water environment.

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