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ORIGINAL PAPER

Foraminiferal assemblage, microfacies analysis, and depositional environment of Tanjero Formation (Late Cretaceous) in Hujran section, Northeast Erbil City, Kurdistan Region, Iraq

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Abstract

The depositional environment of the Tanjero Formation has been studied depending on foraminiferal assemblage and microfacies analysis in the Hujran section, northeast of Erbil City (Iraqi Kurdistan Region). The formation in the studied section consists of 30 m of thin bedded yellowish blue marly limestone interbedded with blue marl in the lower part, whereas the upper part consists of thin yellow limestone and yellowish blue marly limestone interbedded with gray marl, shale, and sand. The foraminifera species are extracted from fourteen samples of friable sediments in the studied section. The result shows that the planktonic and benthonic foraminifera have a high abundance and diversity. Based on the ratio of planktonic/total (planktonic + benthonic) %, the paleodepth of the friable rocks of Tanjero Formation in the Hujran section is mostly upper slope with occasional intervals back to the outer shelf. The petrographic components of 15 thin sections of carbonate rocks of the Tanjero Formation include skeletal grains which are planktonic foraminifera, benthonic foraminifera, calcispheres, echinoid spines, ostracoda, bryozoa, brachiopods, bivalves, and bioclasts. Non-skeletal grains contain only extraclasts of monocrystalline quartz. The main groundmass is composed of micrite with some microspars. Three main microfacies were recognized in the Tanjero carbonates. They are grouped into one basic type of facies association based on their environmental interpretation, which is the deep shelf and lower slope. The proposed depositional environment of the Tanjero Formation is a deep shelf and slope environment depending on field observation, foraminiferal content of friable rocks, and microfacies analysis of carbonate rocks.

Keywords Depositional environment · Foraminifera · Late Cretaceous · Tanjero · Kurdistan Region–Iraq

Introduction

The Tanjero Formation represents the foreland basin of Iraq and belongs to the upper part of the Tectonostratigraphic Megasequences (AP9) of Sharland et al. (2001). The formation was first described by Dunnington, in 1952, in its type locality in the Sirwan Valley, southeast of Sulaimaniya (Bellen et al. 1959). This area is structurally belonging to the Imbricated Zone (Buday 1980). The Tanjero Formation consists of globigerina marls and marly limestone with silt in the lower part and silty marls, siltstones, sandstones, conglomerates, and sandy or detrital limestones in the upper part (Bellen et al. 1959).

The Tanjero Formation is widely distributed as outcrops in the area of northeastern parts of Iraq, and it is very rare in the subsurface wells. It is characterized by abundant fossils particularly planktonic fauna which indicates Maastrichtian age (Abdel-Kireem 1983; Farouk et al. 2018a). It is laterally changed to Aqra/Bekhme and Shiranish Formations toward northwest Iraq and Hartha and Tayarat Formations in central and western Iraq (Jassim and Buday 2006; Mohammed et al. 2022). The Tanjero Formation crops out in southeast Iran that is called Maastrichtian flysch (Kent et al. 1951), while in Turkey it is equivalent to the Cretaceous part of the Garmav Formation (Buday 1980).

Since the first description by Dunnington (1952 in Bellen et al. 1959) the formation was studied by many authors from paleontological, sedimentological, and stratigraphical

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points of view (e.g., Kassab 1975; Al – Rawi 1981; Abdel – Kireem 1986a, b; Jaza 1992; Al – Rawi and Al-Rawi 2002; Karim 2004; 2006; Karim and Surdashy 2005a; 2005b; 2006; Sharbazheri 2007; 2008; Al – Okidee 2013; Pasha 2014; Al-Zubaidi et al. 2016 and Karim et al. 2020). Only rare attempts were made by researchers in the north Erbil especially in the Shaqlawa area. The main aim of the present study is to determine the proper depositional environment of the Tanjero Formation in the Hujran section based on the foraminiferal content and microfacies analysis of its friable and hard rocks, respectively.

Geologic setting

The Tanjero Basin is located in the northern part of the Arabian Plate during the Late Cretaceous, and the formation covers a wide area along the Iranian border. The geological evolution of the basin was controlled by the Late Cretaceous northward subduction of the Arabian Plate (Karim 2004; Karim et al. 2007). The depositional history of the Cretaceous basin consisting of the Tanjero Formation has been subjected to some paleotectonic evolution (Karim and Surdashy 2005b). The Qulqula Radiolarian Formation is the only source rock in these tectonic evolution models on the northern margin of the basin feeding the Shiranish, Tanjero, and Kolosh Formations and the Red Bed Series. The Balambo Formation is located under the accretionary prism and overthrusted by the Qulqula Radiolarian Formation, so it does not crop out anywhere to be a source for the basin during the Upper Cretaceous. The Tanjero Formation is an Upper Cretaceous (Maastrichtian) unit, which crops out within the Imbricated and High Folded Zones in northeastern Iraq. It stretches like a narrow northwest–southeast belt near and more or less parallel to the Iranian border (Karim et al. 2020).

The Hujran section that has been chosen for the present study is located 5 km southwest of Shaqlawa Town. This section is near the Hujran Village and 32 km northeast of Erbil City on lat. 36° 25′ 14″ N and long. 44° 15′ 46″ E, structurally situated in the southern limb of the Safin anticline in the High Folded Zone (Fig. 1a and b).

Stratigraphically, the section involves a stratigraphic succession, starting from Qamchuqa in the core of the Safin anticline and Bekhme, Shiranish, and Tanjero Formations from Cretaceous. The latter is overlain by Kolosh, Khurmala, Gercus, Pila Spi, Fatha (Lower Fars), and Injana (Upper Fars) Formations from Tertiary (Fig. 1a).

The total thickness of the Tanjero Formation in the Hujran section is about 30 m (Fig. 2a). It consists of the thin (10–30 cm) beds of yellowish blue marly limestone with conchoidal fracture interbedded with blue marl in the lower part (Fig. 2b) and thin (10–30) yellow limestone and yellowish blue marly limestone interbedded with gray marl, shale, and sand in the middle and upper parts (Fig. 2c). The nature of the lower and upper boundaries of the formation is unclear due to sedimentary cover (Fig. 2a). However, it sets over Campanian–Early Maastrichtian Shiranish Formation and underlines the Paleocene Kolosh Formation, which they crop out in the southern limb of the Safin anticline.

Methodology

Extensive fieldwork was carried out in the area including the study of the general geology and structural relations of the Cretaceous–Paleogene successions in the surroundings of the studied area in order to choose the suitable section for the present article. The studied outcrop of the Tanjero Formation was described and measured in detail, including the lithology, grain size, and mineralogy. A total of twenty-nine (29) fresh samples (14 friable rocks and 15 hard carbonate rocks) of the Tanjero Formation in Hujran section are collected. The samples were collected at every change in lithology, and/or color (random sampling) for carbonate rocks, and collection intervals range between (2 m) for friable rocks.

Later, the friable sediments and partially consolidated hard rocks (of 50 g weight) were soaked in water overnight; sometimes hydrogen peroxide (10%) is added with water or after the overnight soaking. Then, two spoonfuls of sodium bicarbonate (Na_2HCO_3) were added, and the cooking operation was started on a hot plate for more than 3 h. The samples were washed with tap water to remove clay, and cleared residues were dried in the oven. Different sieves sizes were used (of meshes 10, 20, 40, 60, 80, 100) to separate the sediments into different fractions to be ready for study under a reflected light microscope. The microfossils especially, foraminifera, were picked, identified, and mounted for a permanent record. Over 30 slides were prepared for the study of the biocontents.

A total of 15 thin sections, at least one thin section for each sample of carbonate rocks, were prepared. The thin sections were done in the workshops of the Earth Sciences and Petroleum Department in Salahaddin University-Erbil. All thin sections were oriented and stained with alizarin red S Solution (ARS) following the procedure of Friedman (1959) for the identification of calcite and dolomite. Detailed petrographic study and microfacies analysis were done by using a polarized microscope and based mainly on the Dunham classification (1962).

Results

Foraminiferal assemblage

Picking and mounting of the sand, shale, and marl rocks of the Tanjero Formation in the studied section led to identifying 21 planktonic foraminifera species (Figs. 3, 4, and 5)

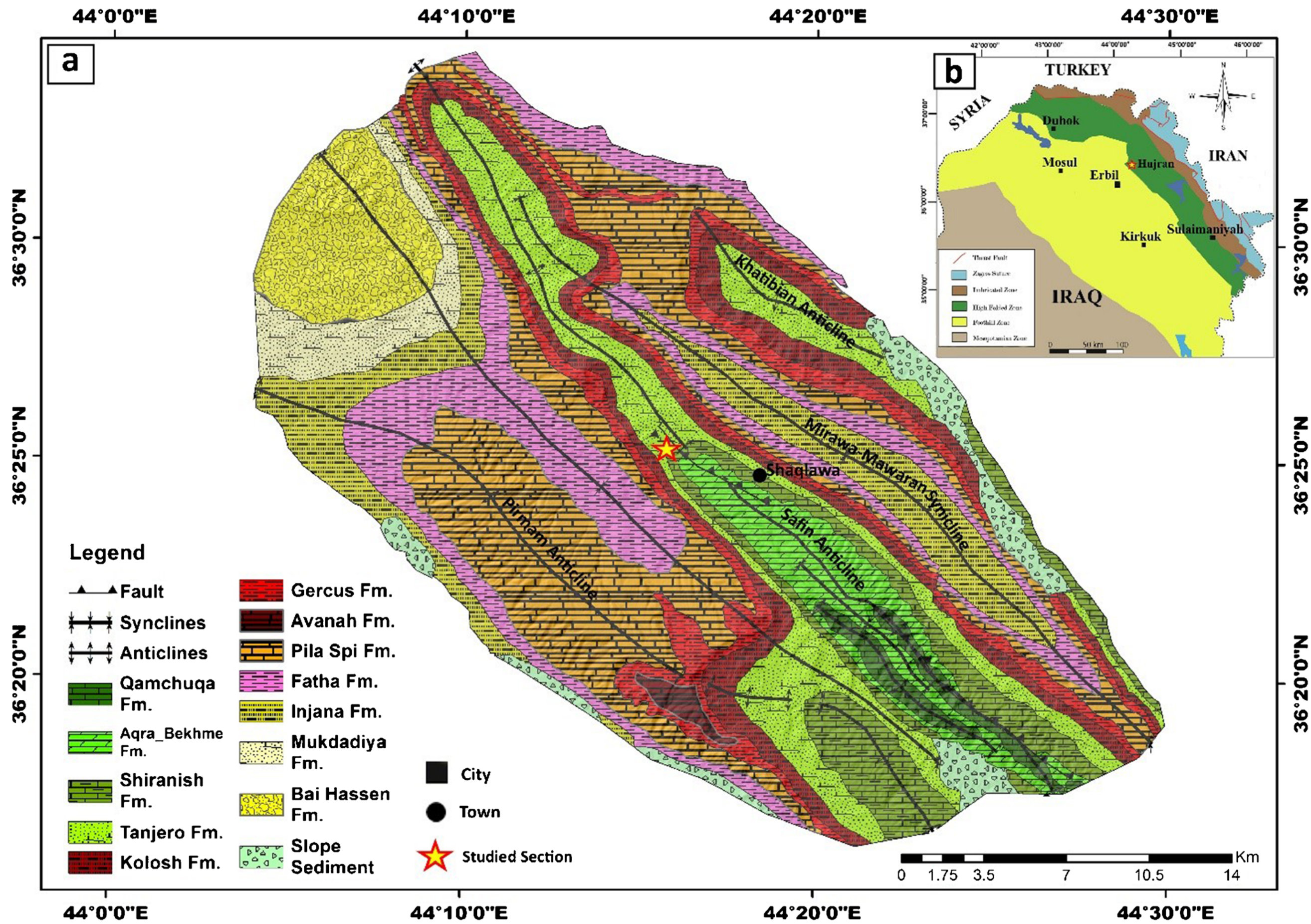

Fig. 1 a) Geological and structural map of the studied area including the studied section, modified from Sissakian and Fouad (2014). b) Location and tectonic map of the studied area (after Jassim and Goff, 2006)

and 22 benthonic foraminifera species (Figs. 3 and 5). The identification of this species is mainly based on Loeblich and Tappan (1964, 1988), Postuma (1971), Robaszynski et al. (1984), Caron (1985), and Tshakreen and Gasinski (2004).

The foraminiferal content of the Tanjero friable sediments displays the predominance of the planktonic and benthonic foraminifera and shows a high diversity of them where the numbers of each form exceed 10. The identifying species in addition to the numbers of keeled and non-keeled planktonic foraminifera have great importance in recognition of the depositional environment of the studied formation. The depositional environment of the formation was determined depending on the classification of Grimsdale and Morkhoven (1955 in Boltovskoy and Wright 1976) and Olsson and Nyong (1984), which are both based on the equation (planktonic/total (planktonic + benthonic) × 100%) (Table 1) (Fig. 6).

Microfacies analysis

The petrographic study of 15 thin sections of Tanjero carbonate in the Hujran section revealed that the main skeletal grains include planktonic foraminifera (*Hedbergella* sp. (Fig. 7a), *Heterohelix* sp. (Fig. 7a and b), *Globotruncana* spp. (Fig. 7b and c), *Globigerinelliodes* sp. (Fig. 7c), *Rugoglobigerina* sp. (Fig. 8d), and *Abathomphalus* sp. (Fig. 7d)). The benthonic foraminifera include *Rotalia* sp. (Fig. 7b and f), *Lenticulina* sp. (Fig. 8a), *Nodosaria* sp. (Fig. 9c), and *Accordiella* sp. (Fig. 8c), whereas other skeletal grains are calcispheres (Figs. 7d and 8f), echinoid spines (Fig. 9a and e), Ostracoda (Fig. 8e), Bryozoa (Fig. 9c and e), brachiopods (Fig. 8f), bivalves (Fig. 8e), and bioclasts (Fig. 9b and e). The non-skeletal grains involve extraclasts which are mainly monocrystalline quartz (Fig. 9b). The dominant groundmass of these rocks is micrite which occasionally transformed to microspar due to neomorphism and silicification. Based on Dunham (1962), three main microfacies types are recognized in the carbonate rocks of the Tanjero Formation. Each was later subdivided into several submicrofacies, based on significant fossil types. Then, these facies were compared with the Facies Zone (FZ) of Wilson (1975) and Standard Microfacies (SMF) of Flügel (1982) to verify the equivalence between both sets. The following are the main

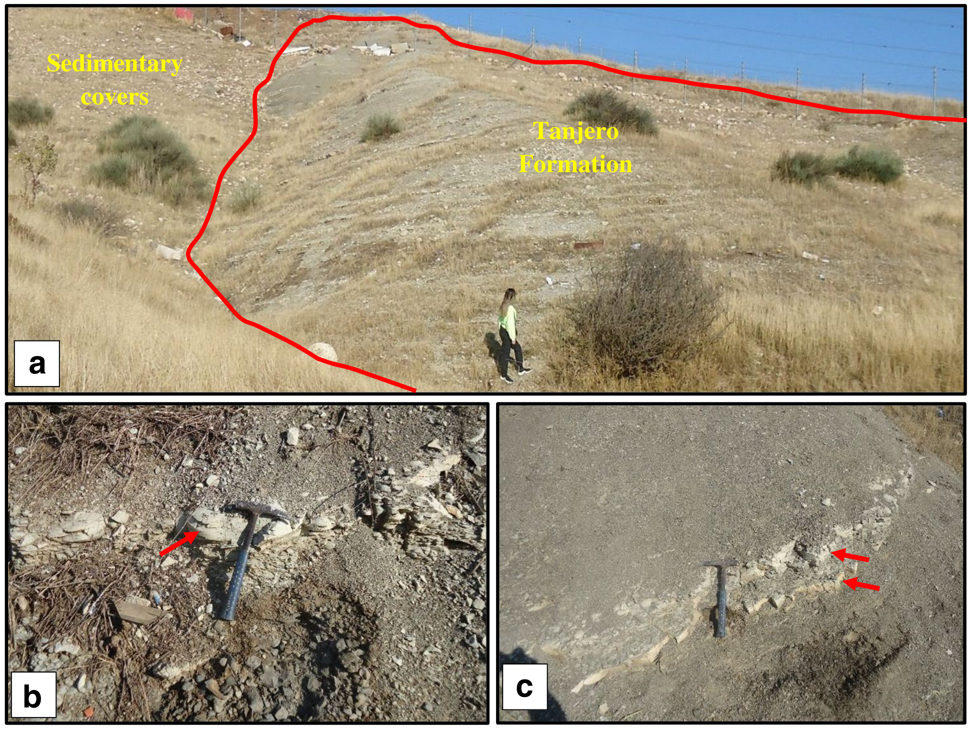

Fig. 2 Field photographs showing a) thin marly limestone beds interbedded with marl and shale of Tanjero Formation in the Hujran section. Lower and upper boundaries uncertain due to sedimentary covers. b) Thin bedded blue marly limestone with conchoidal fracture (red arrow) interbedded with blue marl. c) Thin bedded yellow limestone (red arrows) interbedded with gray shale and sand

microfacies recognized upon the petrographic study of the Tanjero Formation (Fig. 10) (Table 2).

Lime mudstone microfacies

This microfacies is a less common facies in the carbonates of the Tanjero Formation in the Hujran section (Fig. 10), which is characterized by containing grains less than 10% in micrite matrix (Dunham 1962). It has one submicrofacies which is planktonic foraminifera lime mudstone submicrofacies characterized by *Hedbergella* sp. and *Heterohelix* sp (Fig. 7a). The main diagenetic processes are neomorphism and pyritization.

Lime wackestone microfacies

This is a common microfacies in the studied section of Tanjero Formation and found in lower and upper parts of the studied section (Fig. 10). It is characterized by containing grains between 10 and 50% in micritic groundmass (Dunham 1962). The main submicrofacies are planktonic foraminifera (Fig. 7b), foraminifera (Figs. 7f and 8a–d), planktonic foraminifera–ostracods–calcispheres (Fig. 7c), planktonic foraminifera calcispheres (Fig. 7d), ostracods–bivalves–planktonic foraminifera (Fig. 8e), brachiopods–foraminifera (Fig. 8f), and echinoids–planktonic foraminifera lime wackestone submicrofacies (Fig. 9a). The observed fossils in this microfacies are planktonic foraminifera (*Hedbergella* sp., *Heterohelix* sp., *Globotruncana* sp., *Globigerinelliodes* sp., *Rugoglobigerina* sp., and *Abathomphalus* sp.), benthonic foraminifera (*Rotalia* sp., *Lenticulina* sp., and *Accordiella* sp.), calcispheres, echinoid spines, ostracods, bivalves, and brachiopods. It is mainly subjected to cementation, pyritization, and neomorphism diagenetic processes.

Lime packstone microfacies

This microfacies is common in the intervals of the middle part of the Tanjero Formation in the studied section (Fig. 10). Skeletal grains increase up to 60%, leaving minor micrite or microspar in between grain-supported limestone (Dunham 1962). It includes sandy–foraminifera (Fig. 9b) and bioclast–fossiliferous–bioclast lime packstone submicrofacies (Fig. 9c–f). The main skeletal grains of this microfacies are planktonic foraminifera (*Globigerinelliodes* sp.), benthonic foraminifera (*Nodosaria* sp., *Spirloculina* sp., and *Rotalia* sp.), Bryozoa, echinoid spines, calcispheres, and bioclasts, while non-skeletal grains include monocrystalline quartz. It is mainly affected by silicification, cementation, and neomorphism.

Depositional environments

The Tanjero Formation in the Hujran section was deposited in a slope environment. This is confirmed by its

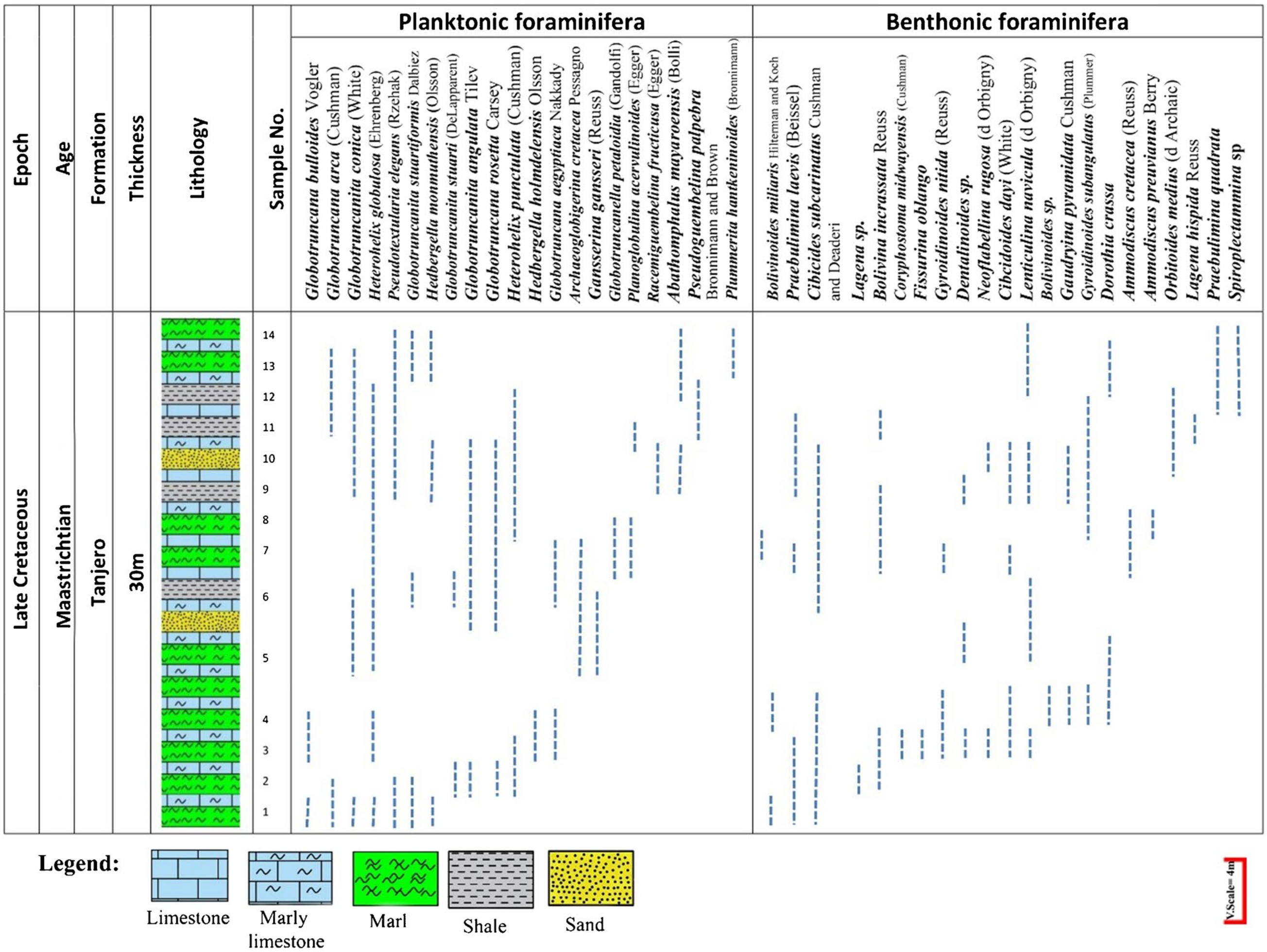

Fig. 3 Foraminiferal distribution in Tanjero Formation in Hujran section

foraminiferal content in its friable rocks. According to the ratio of planktonic/total (planktonic + benthonic) %, the paleodepth of the Tanjero rocks in Hujran section mostly reached the upper slope with occasional intervals back to the outer shelf and middle shelf (Grimsdale and Morkhoven 1955; Farouk et al. 2018b; 2021) and mostly outer shelf with intervals toward the upper slope (Olsson and Nyong 1984). The diversity of the planktonic foraminifera increases with the depth of the marine waters which have a normal salinity (35‰) (Armstrong and Brasier 2005), while toward the equator, such generalization can easily be applied to the Cretaceous planktonic foraminiferal fauna (Haq and Boersma. 1998). The predominance of the keeled planktonic foraminifera along the friable sediments of the Tanjero Formation in the studied section reached 11 species among 21 planktonic foraminifera species, showing clear agreement with the suggested depositional environment (upper slope) according to Grimsdale and Morkovhen (1955). It is well known that the keeled Globotruncanidae forms increase toward the slope and open sea, while the non-keeled Heterohelicidae foraminifera are rare, and the reverse case is correct, whereas Heterohelicidae is abundant toward the continental shelf (Sliter 1971; Farouk et al. 2019). The co-occurrence of the benthonic foraminifera, either calcareous or agglutinated, indicates certain paleodepth of the sediments. The middle slope is suggested for the taxa of *Praebulimina*, *Spiroplectammina*, and *Dorothia* by Sliter and Baker (1972). Li et al. (1999) recorded the presence of *Praebulimina* and *Lenticulina* from the outer shelf, while the last genus was considered, with *Bolivina* as indicators for outer shelf–upper slope (Sliter and Baker 1972).

The number of agglutinated forms in Tanjero sediments reaches 5 species in the Hujran section. The majority of these forms are *Ammodiscus cretacea*, *Ammodiscus preuvianus*, *Dorothia crassa*, *Gaudryina pyramidata*, and

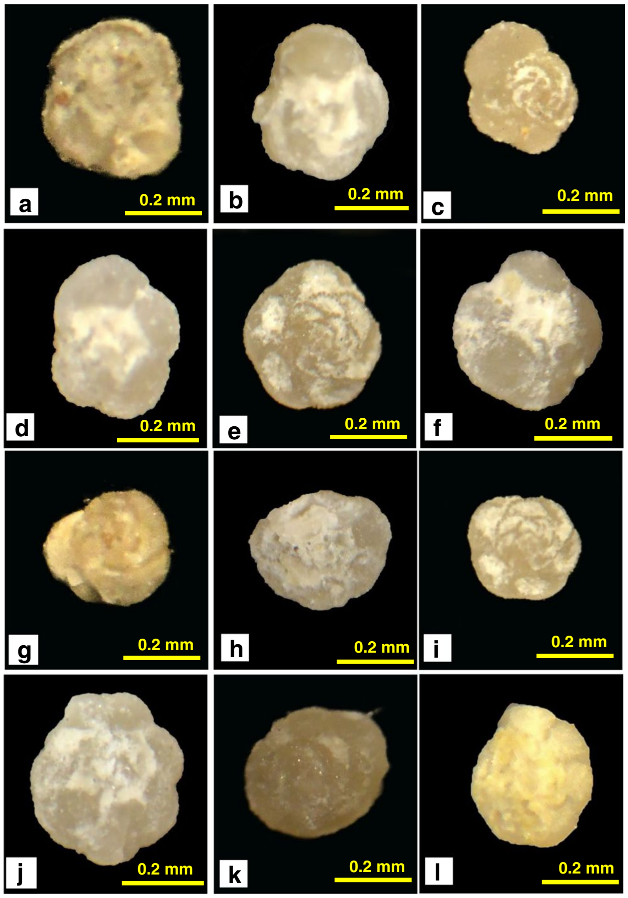

Fig. 4 Planktonic foraminifera taxa in Tanjero Formation showing a, b) *Abathomphalus mayaroensis*: a) spiral side; b) umbilical side. TF 12. c, d) *Globotruncana aegyptiaca* Nakkady: c) spiral side; d) umbilical side. TF6. e, f) *Globotruncana arca* (Cushman): e) spiral side; f) umbilical side. TF.11. g, h) *Globotruncana bulloides* Vogler: g) spiral side; h) umbilical side. TF3. i, j) *Globotruncana rosetta* Carsey: i) spiral side; j) umbilical side. TF5. k, l) *Globotruncanita conica* (White): k) spiral side; l) umbilical side. TF6. Key: T Tanjero, F friable rocks

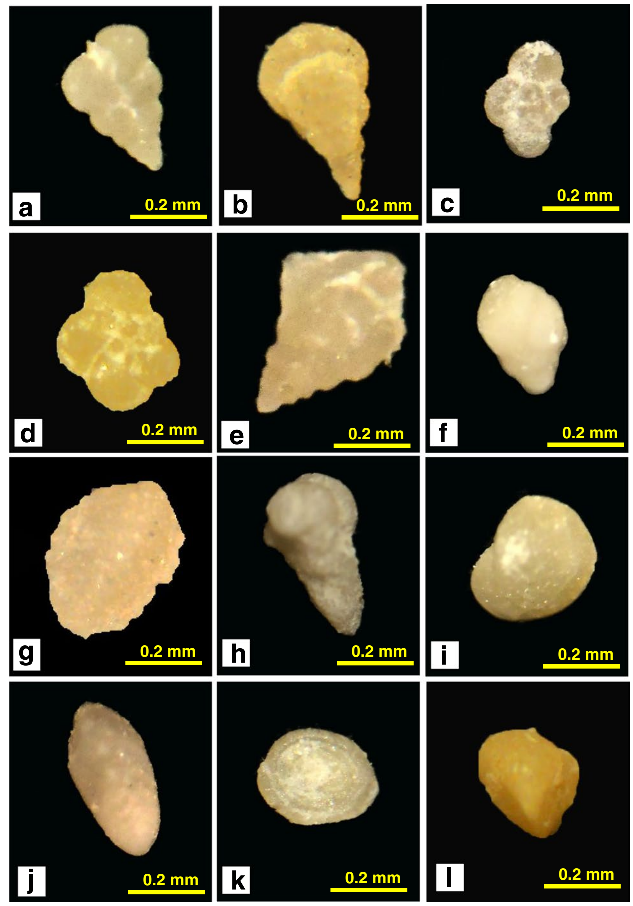

Fig. 5 a–e) Planktonic foraminifera taxa in Tanjero Formation showing a) *Heterohelix globulosa* (Ehrenberg). TF10. b) *Pseudotextularia elegans* (Rzehak), TF12. c) *Hedbergella holmdelensis* Olsson. TF 14. d) *Archaeoglobigerina cretacea* Pessagno. TF6. e) *Plummerita hantkeninoides* (Bronnimann). TF11. f–l) Benthonic foraminifera taxa in Tanjero Formation displaying: f) *Praebulimina laevis* (Beissel). TF2. g) *Spiroplectammina* sp. TF13. h) *Dorothia* sp. TF.12. i) *Lenticulina navicula* (d'Orbigny) TF11. j) *Bolivina* sp. TF7. k) *Ammodiscus cretacea* (Reuss). TF6. l) *Gaudryina pyramidata* Cushman. TF8

Spiroplectammina, which were identified from mostly the outer shelf–upper slope.

From the above investigations, the depositional environment of Tanjero Formation could be upper slope (Grimsdale and Morkhoven 1955) or outer shelf (Olsson and Nyong 1984) with rare sediment samples that have accumulated at the middle shelf and middle slope. The latter is more acceptable for interpretation of the Tanjero depositional settings. The suggested outer shelf–upper slope paleodepth for the studied sediments is supported also by the approximate equilibrium between the diversity of keeled and non-keeled foraminifera.

The occurrence of the other keeled *Globotruncana* taxa along with some epipelagic non-keeled taxa such as *Heterohelix*, *Pseudotextularia*, *Hedbergella*, and *Archaeoglobigerina* indicates the outer shelf–the upper slope of the latest Maastrichtian sediments (Tshakreen and Gasinski 2004).

Table 1 Percentages of planktonic/total % corresponding to their depositional environments according to Grimsdale and Morkhoven (1955) and Olsson and Nyong (1984)

Grimsdale and Morkhoven (1955)	Olsson and Nyong (1984)
Inner shelf < 15%	
Middle shelf 15–30%	Middle shelf 8–30%
Outer shelf > 30–50%	Outer shelf > 30–70%
Upper slope > 50–75%	Upper slope > 70–90%
Middle slope > 75–90%	Middle slope > 90%
Abyssal and hadal > 90%	

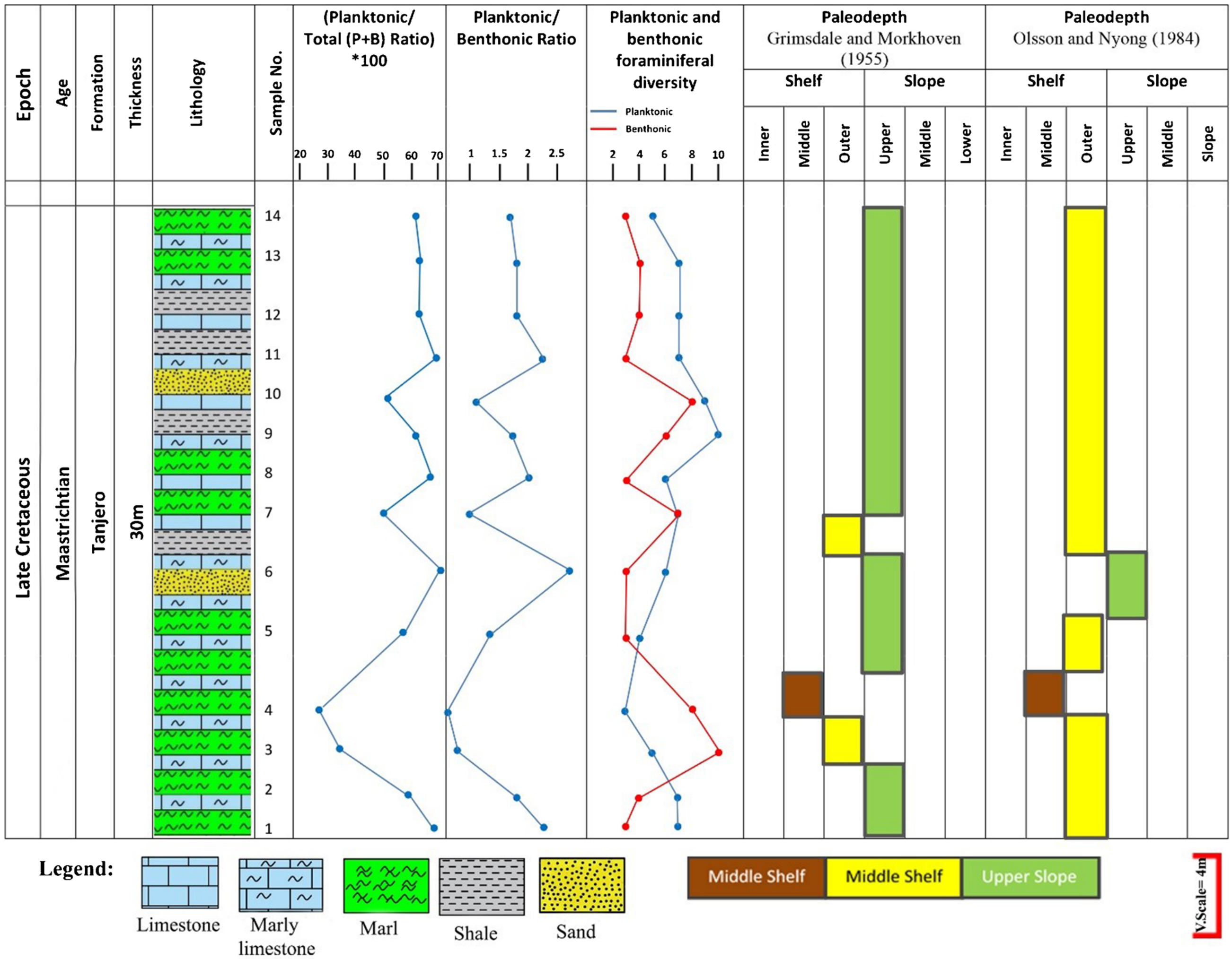

Fig. 6 Suggested paleoenvironments of Tanjero Formation in Hujran section according to foraminiferal content

On the other hand, one facies association (FA) was recognized from the microfacies analysis of Tanjero carbonates which is a deep shelf and lower slope facies association. This association is equivalent to Facies Zone 3 of Wilson (1975) and Standard Microfacies SMF 3 and 4 of Flügel (1982). The dominance of planktonic foraminifera in the carbonate rocks of the studied section indicates an open marine and bathyal basin (Flügel 2010). The occurrence of a rare number of benthonic foraminifera with a high proportion of pelagic faunas is considered autochthonous benthic fossils in the deep shelf environment (Wilson 1975; Flügel 2010). Calcispheres which are associated with planktonic foraminifera in the studied section have an unknown systematic affinity, and are considered traces or remnants of planktonic organisms (Andri 1972 in Bein 1977; Khalifa et al, 2016). Calcispheres can be found in deposits of both shallow and deep water (Masters and Scott 1978), but in the present study, the deep shelf origin of Tanjero calcispheres is more acceptable because of their associations with pelagic organisms (Balaky et al. 2016). Ostracods, which are highly obliterated, are inhabitants of several environments, marine, transitional, and fresh, and are found at various depths from the shoreline to bathyal depths and have a wide distribution from the equator to polar seas (Haq and Boersma 1998). Brachiopods which are rarely found in the middle part of the studied section live in a different environment and may occur deeper than 2000 m (Zezina 2012). The association of ostracods and brachiopods with other pelagic fossils indicates a deep shelf setting. Echinoid spines are common in normal marine, open-shelf deposits (Scholle and Ulmer-Scholle

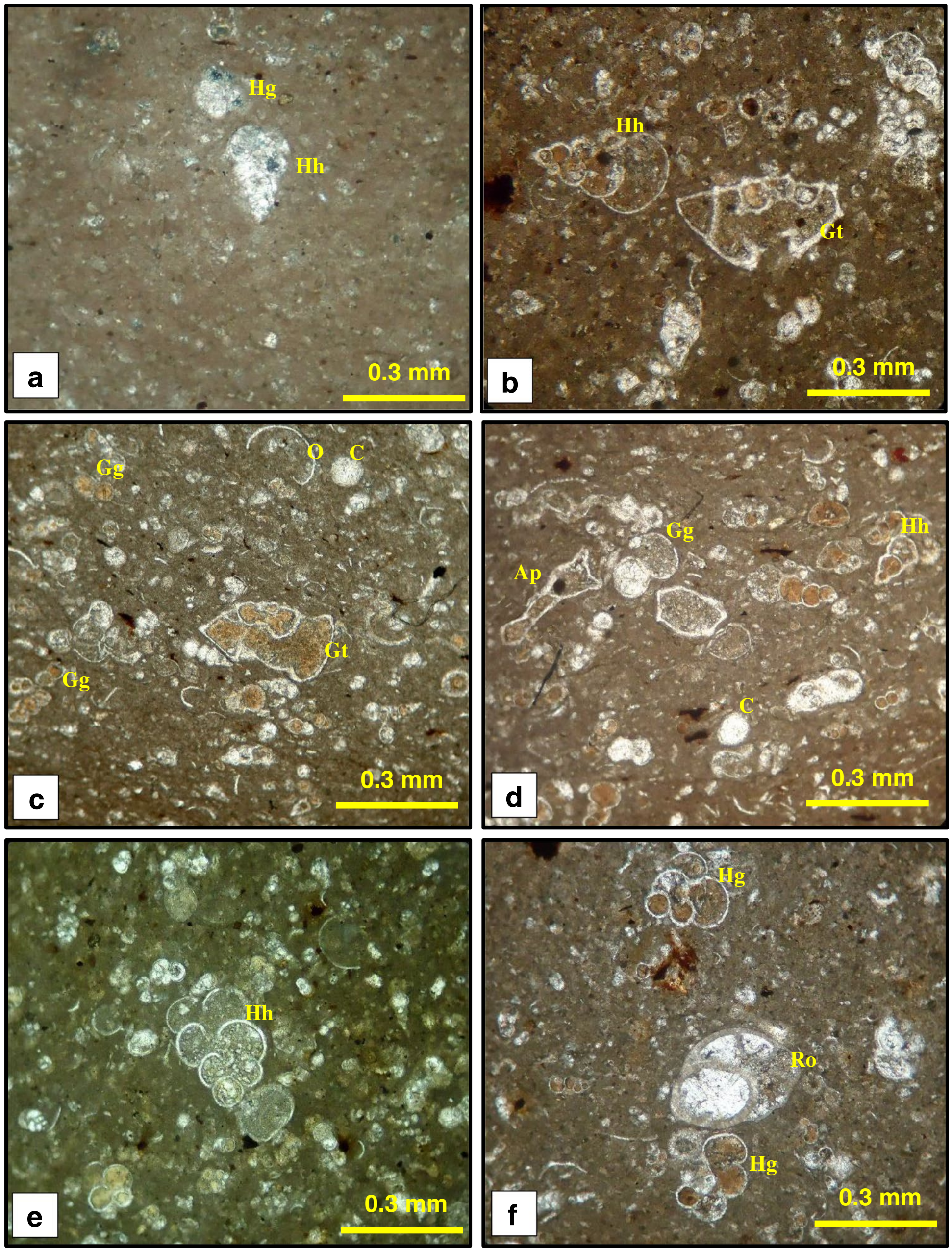

Fig. 7 Photomicrographs of the carbonate rocks of the Tanjero Formation in Hujran section showing microfacies types. a) Planktonic foraminifera lime mudstone microfacies include *Heterohelix* sp. (Hh) and *Hedbergella* sp. (Hg). TC.15., P.P. b) Planktonic foraminifera lime wackestone involve *Globotruncana* (Gt) and *Heterohelix* sp. (Hh). TC.2., P.P. c) Planktonic foraminifera–Ostracoda–calcispheres lime wackestone displays *Globotruncana* sp. (Gt), *Globigerinelliodes* (Gg), Ostracoda valve (O), and calcispheres (C). TC.3., P.P. d) Planktonic foraminifera–calcispheres lime wackestone microfacies include *Abathomphalus mayaroensis* (Ap), *Globigerinelliodes* (Gg), *Heterohelix* sp. (Hh), and calcispheres (C). TC.4., P.P. e) Planktonic foraminifera wackestone microfacies include *Heterohelix* (Hh). T., P.P. f) Foraminifera wackestone microfacies including *Rotalia* sp. (Ro) and *Hedbergella* sp. (Hg). TC.1., P.P. Key: TC Tanjero carbonate, P.P. plane-polarized light, X.R crossed nicols, A.S. alizarin stained

2003). Bioforms and bioclasts including bivalves, bryozoans, echinoderms, and foraminifera with extraclasts which is monocrystalline quartz in packstone microfacies which occupied the most upper interval of the middle part of the studied section supposed to be locally derived bioclasts and imported shallow-water material indicating toe-of-slope settings (Flügel 2010; Hewaidy et al. 2016; Hewaidy et al. 2017; Farouk et al. 2016).

From the above interpretation, it is here concluded that the depositional environment of the Tanjero Formation in the Hujran section is a deep shelf and slope environment.

Discussion

The Tanjero Formation in the Hujran section comprised thin-bedded marly limestone and limestone interbedded with friable rocks (shale, marl, and sand). This interbedding between carbonate rocks and friable rocks reflects that the formation in the studied section was deposited in the slope environment, which includes fluctuating intervals of shallowing and deepening upward of the sedimentary facies. The shallowing upward facies represented by shale, marl, and sand rocks show high

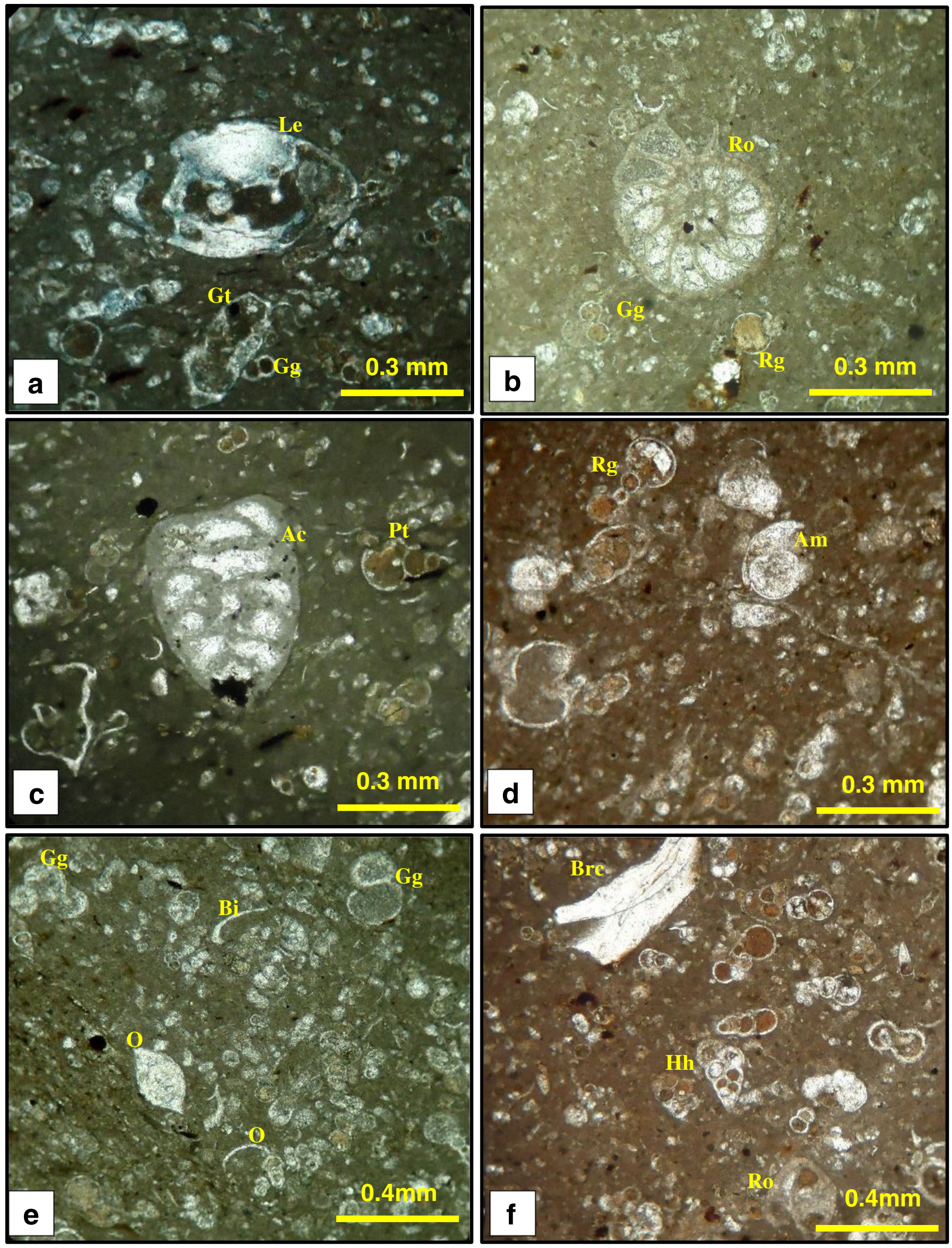

Fig. 8 Photomicrographs of the carbonate rocks of the Tanjero Formation in Hujran section showing microfacies types. a–d) Foraminifera lime wackestone displays a) *Lenticulina* sp. and *Globotruncana* sp. TC.3., X.N. b) *Rotalia* sp. (Ro), *Globigerinelliodes* sp. (Gg), and *Rugoglobigerina* (Rg). TC.2., P.P. c) *Accordiella* sp. (Ac) and *Pseudotextularia* (Pt). TC.3, P.P. d) *Ammodiscus* sp. (Am) and *Rugoglobigerina* sp. (Rg). TC.8., P.P. e) Ostracods (O)–bivalves (Bi)–planktonic foraminifera (*Globigerinelliodes* sp. (Gg)) wackestone microfacies. TC.7, P.P. f) Brachiopods (Brc)–foraminifera wackestone microfacies including *Rotalia* sp. (Ro) and *Hedbergella* sp. (Hg). TC.1, P.P. Key: TC Tanjero carbonate, P.P. plane-polarized light, X.R crossed nicols, A.S. alizarin stained

foraminiferal contents that are mostly accumulated in the outer shelf–upper slope environment, whereas the fining upward facies are represented by the thin carbonate beds which are supposed to be a deep shelf–lower slope environment, as indicated by their microfacies analysis. From the microfacies point view of the Tanjero carbonates in the studied section, is mainly lime wackestone microfacies that indicates a relatively low- to the medium-energy regime and changed to lime packstone microfacies in two intervals in the middle part. This means the deposition happened in the higher energy regime than the lime wackestone microfacies and it was changed to lime mudstone microfacies in the upper part which refers to the quiet sea bottom and low-energy regime in the upper part of the studied section (Núñez-Useche and Barragán 2012) (Fig. 10). This fluctuation in the sea level is due to the unstable nature of the Tanjero Basin in the whole Kurdistan Region. Jassim and Goff (2006) supposed that it was deposited as flysch in a rapidly subsiding foredeep basin immediately in front of the thrust sheets of the obducted margin of the southern Neo-Tethys Ocean. The turbidite deposition of the Tanjero Formation has been proposed

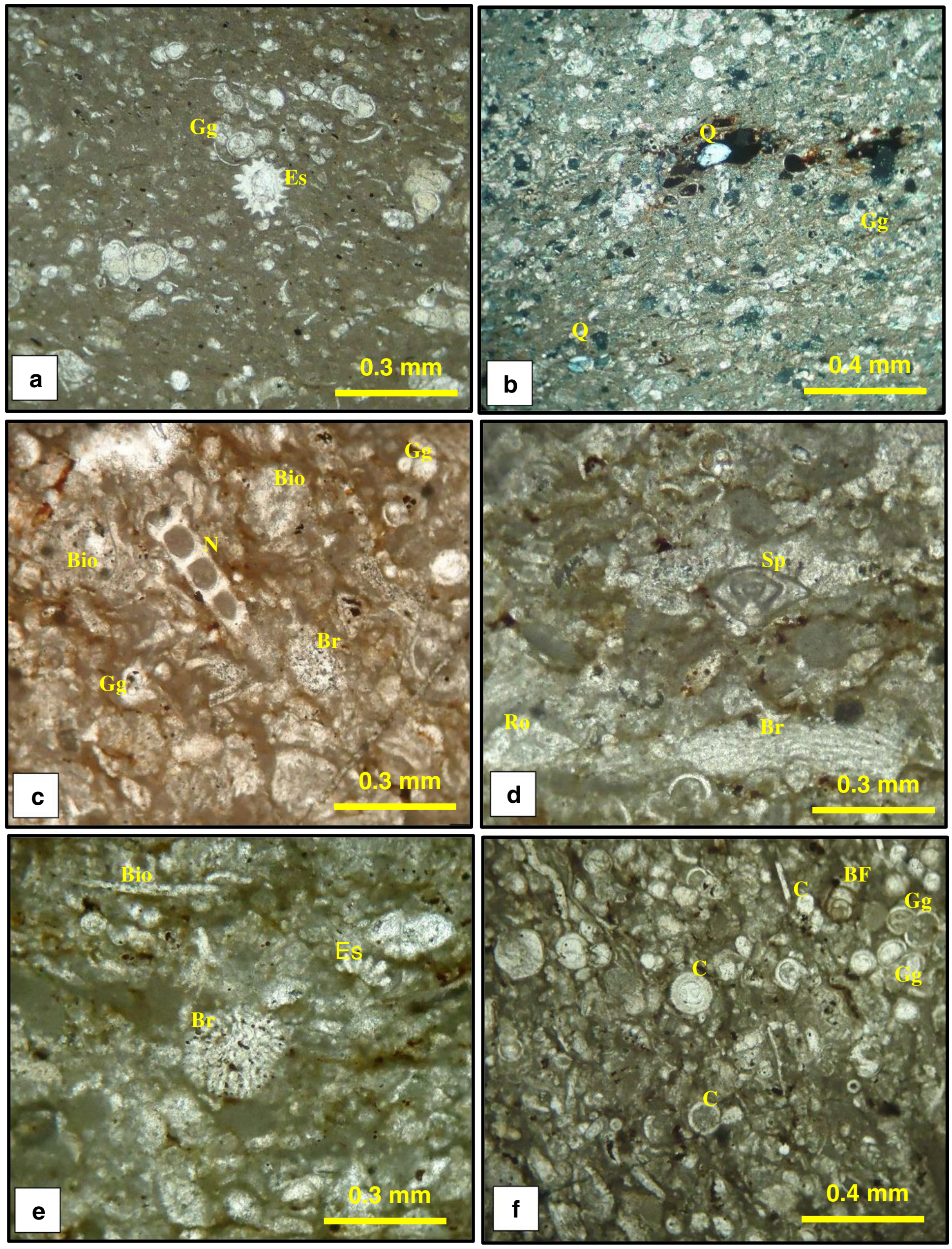

Fig. 9 Photomicrographs of the carbonate rocks of the Tanjero Formation in Hujran section showing microfacies types. a) Echinoids–planktonic foraminifera lime wackestone displays echinoid spines (Es) and *Globigerinelliodes* sp. (Gg). TC.8., P.P. b) Sandy–foraminifera–bioclast lime packstone microfacies. TC.6. X.N. c–f) Fossiliferous–bioclasts lime packstone includes c) Bryozoa (Br)–bioclast (Bio), *Globigerinelliodes* sp. (Gg), and *Nodosaria* sp. (No). TC.10. d) Bryozoa (Br), *Spirloculina* sp. (Sp), and *Rotalia* sp. (Ro). TC.5., P.P. e) Bryozoa (Br), echinoids (Es), bioclasts (Bio). f) Calcispheres (C), *Globigerinelliodes* sp. (Gg), and biserial benthonic foraminifera (BF). TC.6., P.P. Key: T Tanjero, P.P. plane-polarized light, X.R crossed nicols, A.S. alizarin stained

by many previous works, e.g., Karim (2004) and Karim et al. (2020). Generally, the lithology of Tanjero Formation in the lower part of the studied section resembles the hemipelagic facies of the formation in Goizha and Azmir sections and consists of bluish marl interbedded with marly limestone, while in the upper part, it is closer to the terrigenous sandy mudstone facies which consists of olive-green sandy mudstone (calcareous shale) (Karim 2004). The dominance of marl with less common shale and sand interbedded with thin carbonate beds in the studied section indicates that it is deposited in a deep-water environment (slope) during slight turbidite water (Karim 2004). The microfacies of the Tanjero carbonates in the studied section relatively correspond with the microfacies of the carbonate rocks of the Tanjero Formation in the Dukan section northeast of Sulaimaniya City by Al- Zubaidi et al. (2016), who revealed that it is mostly deposited in the outer shelf and deep marine environment.

From the sum of field observation, foraminiferal contents of friable rocks and microfacies analysis of carbonate rocks suggested that the depositional environment of the Tanjero Formation in the Hujran section is

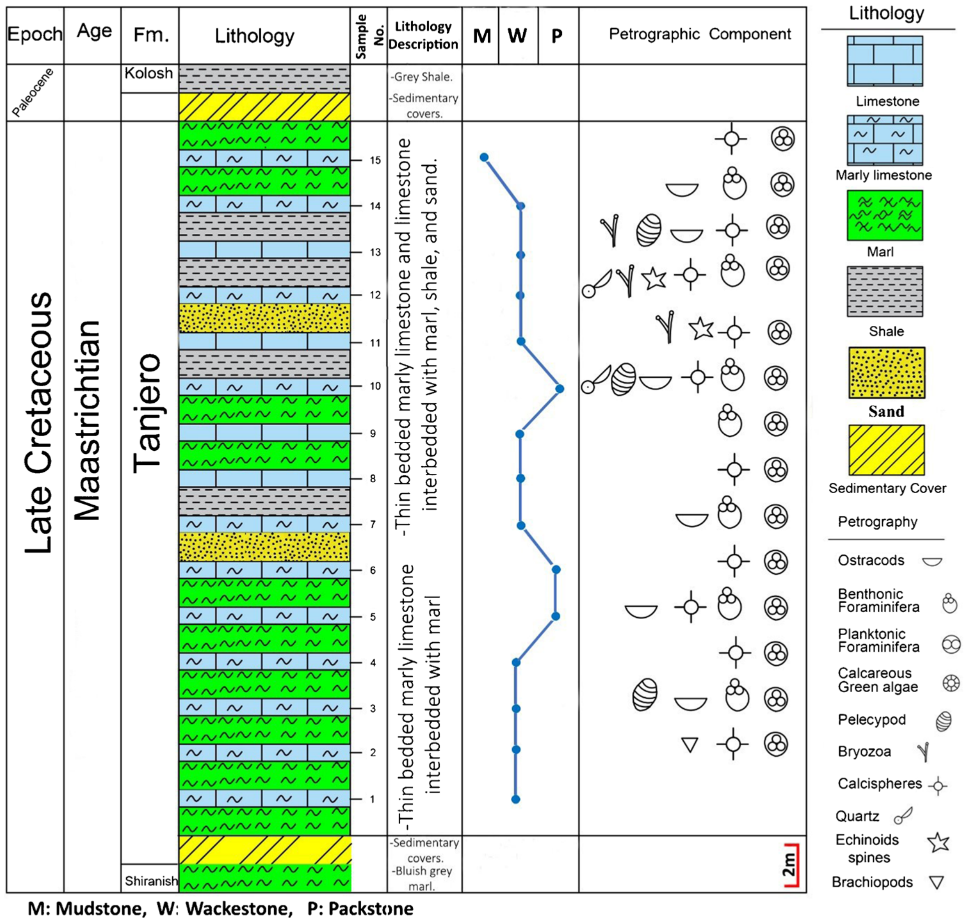

Fig. 10 Columnar section of Tanjero Formation corresponding to microfacies types in Hujran section, High Folded Zone

a deep shelf and slope environment, which is illustrated in the proposed model for the inferred paleoenvironmental setting of the Tanjero Formation in Northeastern Erbil City, High Folded Zone, Kurdistan Region of Iraq (Fig. 11).

Conclusions

1. The foraminiferal content of the Tanjero Formation friable deposited in the Hujran section displays the predominance of the planktonic and benthonic foraminifera, and shows a high diversity of them where the numbers of each form exceed 10.
2. According to the ratio of planktonic/total (planktonic + benthonic) %, the paleodepth of the friable rocks of the Tanjero Formation in the Hujran section mostly reached the upper slope with occasional intervals back to the outer shelf.
3. The petrographic components of carbonate rocks of the Tanjero Formation are represented by skeletal grains including planktonic foraminifera, benthonic foraminifera, calcispheres, echinoid spines, ostracoda, bryozoa, brachiopods, bivalves, and bioclasts, whereas non-skeletal grains contain only extraclasts which are mainly monocrystalline quartz grains. The main groundmass is composed of micrite with some microspar.
4. Depending on the classification of Dunham (1962) and detailed microscopic study, three main microfacies were discriminated in the Tanjero carbonates, grouped into one basic type of facies association based on their environmental interpretation which is a deep shelf and lower slope.
5. From the sum of field observation, foraminiferal contents of friable rocks and microfacies analysis of carbonate rocks suggested that the depositional environment of the Tanjero Formation in the Hujran section is a deep shelf and slope environment including fluctuation of deepening and shallowing facies represented by carbonate rocks and friable rocks, respectively.

Table 2 Main and subdivisions of microfacies of Tanjero Formation

Main microfacies of Dunham (1962)	Subdivision of Dunham's (1962) terms	Diagnositic features (main skeletal grain + common diagenetic process)	SMF of Flügel (1982)	Equivalence to Wilson's (1975) Facies Zone
Lime mudstone	Planktonic foraminifera lime mudstone	- *Heterohelix* + *Hedbergella* - Neomorphism + pyritization	SM 3	FZ 2
Lime wackestone	Planktonic foraminifera lime wackestone	- *Globotruncana* + *Heterohelix* - Neomorphism + pyritization		
	Foraminifera lime wackestone	- *Rotalia* + *Lenticulina* + *Hedbergella* + *Accordiella* + *Ammodiscus* + *Globotruncana* + *Globigerinelliodes* + *Rugoglobigerina* + *Pseudotextularia* - Silicification + neomorphism + Pyritization		
	Planktonic foraminifera–ostracods–calcispheres lime wackestone	- *Globotruncana* + *Globigerinelliodes* + ostracods + calcispheres - Neomorphism + cementation		
	Planktonic foraminifera–calcispheres lime wackestone	- *Abathomphalus* mayaroensis + *Globigerinelliodes* + *Heterohelix* + calcispheres - Neomorphism + cementation		
	Ostracods–bivalves–planktonic foraminifera lime wackestone	- *Globigerinelliodes* + ostracods + bivalves - Pyritization + cementation		
	Brachiopods–foraminifera wackestone	- *Rotalia* + *Hedbergella* + brachiopods - Neomorphism + iron oxidization		
	Echinoids–planktonic foraminifera lime wackestone	- Echinoid spines + *Globigerinelliodes* - Neomorphism		
Lime packstone	Sandy–foraminifera–bioclast lime packstone	- Monocrystalline quartz + *Globigerinelliodes* + bioclasts - Silicification + solution	SM4	
	Fossiliferous–bioclast lime packstone	- Foraminifera + Bryozoa + echinoid spines + calcispheres + bioclasts - Neomorphism + cementation		

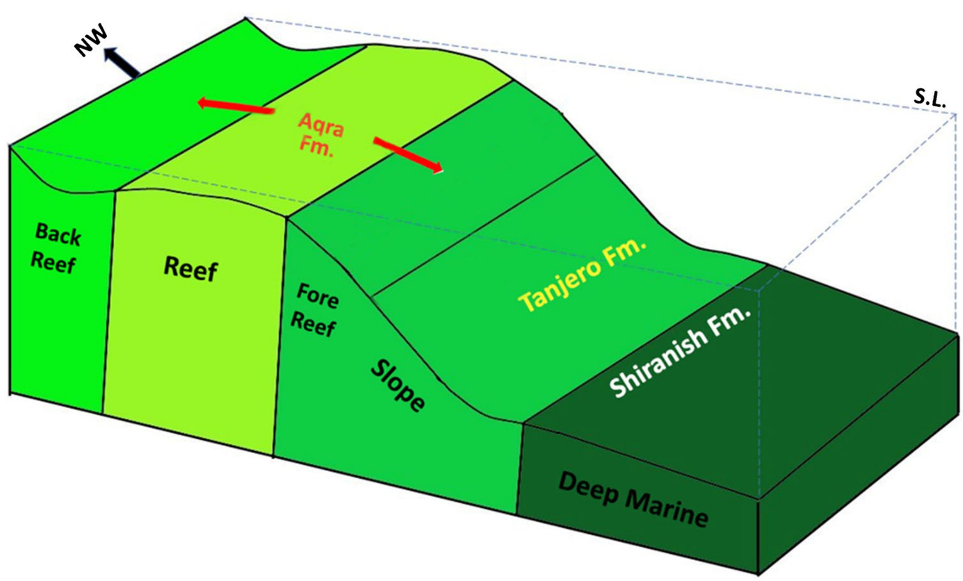

Fig. 11 The depositional model of the Tanjero Formation (Late Cretaceous) at Hujran section, High Folded Zone, northern Iraq

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Declarations

Conflict of interest The authors declare that they have no competing interests.

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