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Biofacies and palaeoecology of the Jahrum Formation in Lar area, Zagros Basin, (SW Iran)

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Abstract

Biofacies and palaeoecology of the limestone of the Jahrum Formation in the Lar area in the southwest of Iran (Zagros Basin) is addressed in this paper. Our detailed analysis of biofacies and palaeoecology shows that the Jahrum Formation in the studied area were deposited in a carbonate open shelf dominated by heterozoan and, subordinately, photozoan skeletal assemblages. Based on analysis of larger benthic foraminiferal assemblages and biofacies features, two major depositional environments are identified. These include inner shelf and middle shelf environments. The inner shelf facies is characterized by wackestone-packstone, dominated by various taxa of imperforate foraminifera. The middle shelf is represented by wackestone-packstone with a diverse assemblage of larger foraminifera with perforate wall. The distribution of the larger benthic foraminifera indicates that shallow marine carbonate sediments of the Jahrum Formation at the studied areas have been deposited in the photic zone of tropical to subtropical oceans.

Keywords*:* Biofacies; Palaeoecology; Jahrum Formation; Eocene; Zagros Basin

1. Introduction

The limestone of Jahrum Formation (Paleocene-Eocene), constitutes one of the reservoir intervals in the Zagros Basin in Iran. The studied area is located in Fars Province (SW Iran), which is part of the Zagros fold-and-thrust belt (Fig. 1) [1, 2]. The Jahrum Formation, the focus of this study, takes its name from the type section at Kuh-e Jahrum in Fars Province. The type section was described by James and Wynd [3]. It is divided into three carbonate units with a total thickness of 467.5 m. This formation transgressivly overlies the silty marl, dolomites and evaporates of the Sachun Formation (Fig. 2) [4]. Where the latter is absent, it overlies either the Pabdeh or Gurpi formations. The upper contact with the Asmari Formation is unconformable. On the Fars area, there is a transition between the Jahrum and Pabdeh Formation. Studies of the Jahrum Formation have focused mainly on their lithostratigraphy and biostratigraphy, James and Wynd [3]; Rahaghi [5]; Kalantari [6]; Hottinger [7]. A few previous studies have been focused on detailed investigation of sedimentological aspects [8-10], however, detailed palaeoenvironmental interpretations and biofacies work is still necessary. Shallow marine carbonate sediments of the Jahrum Formation exhibit a great diversity and abundance of larger foraminifera, and they can be easily identified in thin section and in the field. Consequently, larger foraminifera provide a useful tool for reconstructing paleoenvironments in lithologically monotonous Jahrum successions. The most prominent components of the studied sediments are nummulitids and alveolinids.

This paper examines in detail the biofacies of Jahrum Formation in the Lar area and provides palaeoenvironmental interpretations of the sedimentary succession.

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2. Methods of study

More than 328 thin sections were analyzed under the Petrographic microscope for biofacies composition. The textural classification of Dunham [11] and Embry and Klovan [12] were used to describe biofacies types. The biofacies and assemblages of benthic hyaline and imperforate foraminifera are used in interpreting palaeoenvironmental conditions of the Jahrum Formation.

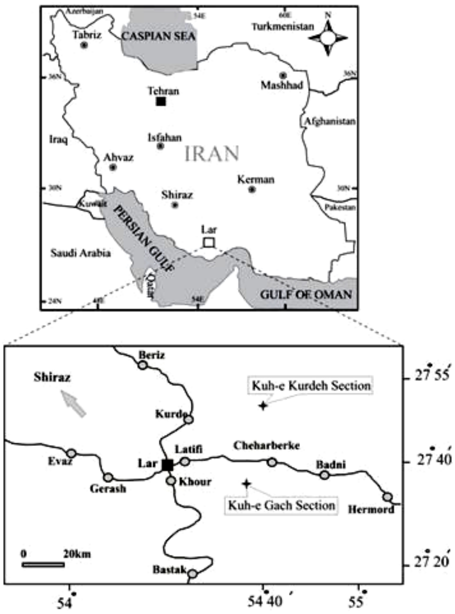


Fig. 1. Location of the studied sections in southwest Iran

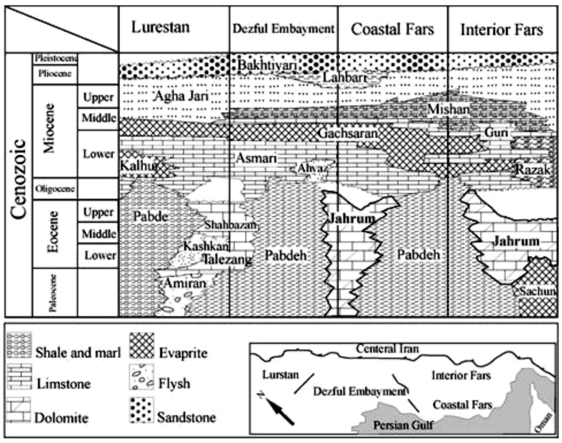
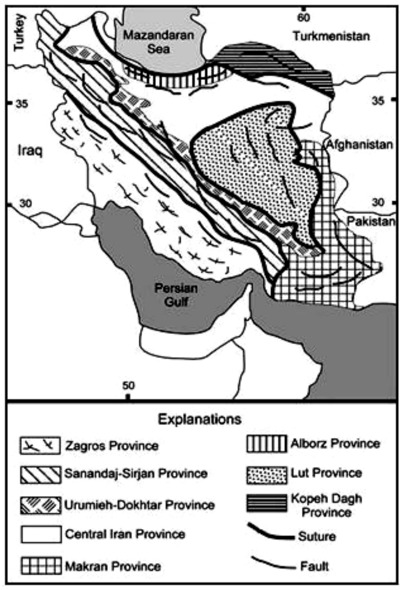


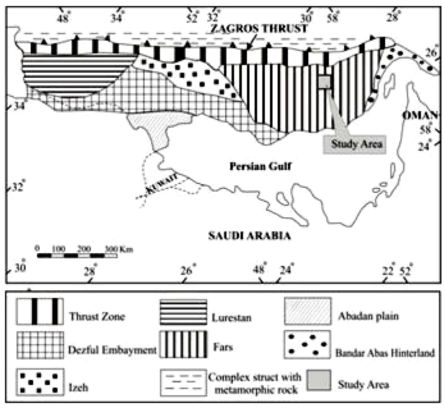
Fig. 2. Cenozoic stratigraphic correlation chart of the Iranian Sector of the Zagros Basin, [4]

3. Geological setting

The Iranian plateau extends over a number of continental fragments welded together along suture zones of oceanic character. Each fragment differs in its sedimentary history, age of magmatism and metamorphism, and its structural character and intensity of deformation [13]. These fragments are in the following provinces: (1) Zagros, (2) Sanandaj-Sirjan, (3) Urumieh-Dokhtar, (4) Central Iran, (5) Alborz, (6) Kopeh Dagh, (7) Lut and (8) Makran (Fig. 3) [14]. The Jahrum Formation is part of the Cenozoic deposits (Paleocene-Eocene) of the Zagros Basin in southwest Iran. The Zagros Mountains and adjacent areas are well-known for their vast huge hydrocarbon reservoirs and very young tectonic activities [2].



(a)



(b)

Fig. 3. (a) General map of Iran showing eight geologic provinces [13], (b) Subdivisions of the Zagros province

The Zagros Basin was a continental margin attached to the eastern edge of Africa during the Phanerozoic. Throughout the Permian, detachment of the Iran plate including Alborz, Central-East-Iran microcontinent, and Sanandaj-Sirjan from the Arabian plate caused the formation of the Neo-Tethys Ocean [1, 15].

The closure of the Neo-Tethys Ocean, mostly during the Late Cretaceous, was because of the subduction of the Arabian plate toward the northeast, beneath the Iranian subplate [13, 16-18].

The Zagros fold-thrust belt resulted from the continent-continent collision between the Arabian margin and the Eurasian Plate, caused the subsequent closure of the Neo-Tethys Ocean during the Cenozoic [19, 20]. The Zagros fold-and-thrust belt of Iran is a result of the Alpine orogenic events [21] in the Alpine-Himalayan mountain range.

This study is based on two outcrop sections in the Lar area (Kuh-e Gach and Kuh-e Kurdeh) (Fig. 4).

Kuh-e Kurdeh section is located about 40 Km northeast of Lar city. This section was measured at 27° 49' 26" N and 54° 40' 9"E. The Kuh-e Gach section is located about 30 Km southeast of Lar City. It was measured in detail at 27° 38' 55" N and 54° 37' 16" E.

The total thickness of the Jahrum Formation is 404.5 m and 437 m in the Kuh-e Gach and Kuh-e Kurdeh sections, respectively.

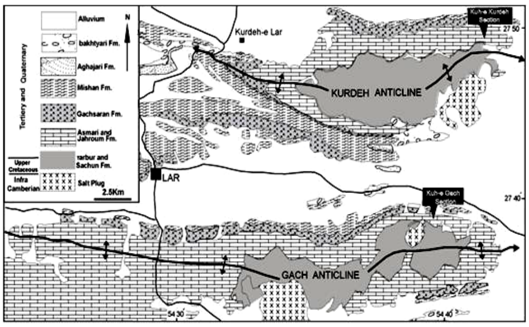


Fig. 4. Location and geological map of the study areas, Kuh-e Gach and Kuh-e Kurdeh Anticline, sw of Iran, Lar area

4. Biofacies analysis

Facies analysis of Jahrum, the Formation in the study area has resulted in recognition of 7 biofacies types (Figs. 5, 6), characterizing platform development (Figs. 7, 8). Each biofacies is characterised by typical skeletal components and textures. The general environmental interpretations of the biofacies are discussed in the following paragraphs.

4.1. Biofacies A. Large and flat nummulitids bioclastic wackestone

The predominate fauna are larger benthic foraminifera with perforate walls (nummulitidae). Nummulitidae are represented by *Operculina* and *Nummulites*. This biofacies has a fine grained matrix. Other bioclasts include *Linderina, Amphistegina* and echinoid.

The foraminifera assemblage of this facies (Fig. 5a) shows close affinities to that described by Cosovic et al. [22] of the Adriatic carbonate platform (Istrian Peninsula) and Taheri et al. [10] of the Jahrum Formation in the Zagros Basin. Such assemblages are characteristic of lower slope carbonate environments.

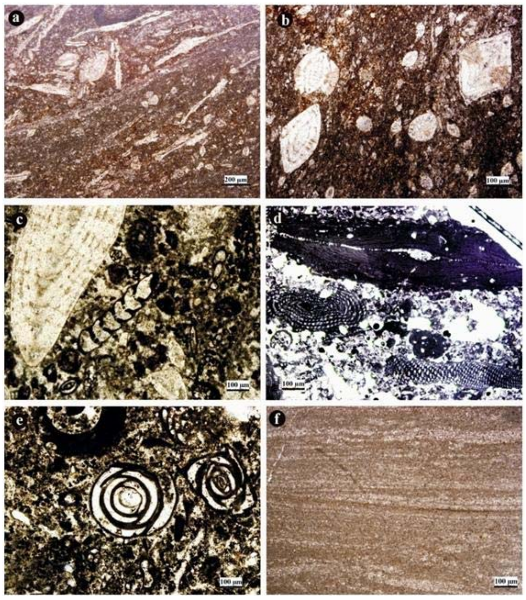


Fig. 5. Microfacies of the Jahrum Formation at Kuh-e Gach section in Lar area. (a) Biofacies A, Large and flat nummulitids bioclastic wackestone. (b) Biofacies B, Lens-shaped nummulitids bioclastic wackestone-packstone. (c) Biofacies C, Foraminifera (perforate and imperforate) bioclastic wackestone-packstone. (d) Biofacies D, High diversity imperforate foraminifera packsotne-grainstone. (e) Biofacies F, Miliolids packstone. (f) Biofacies G, Stromatolitic boundstone

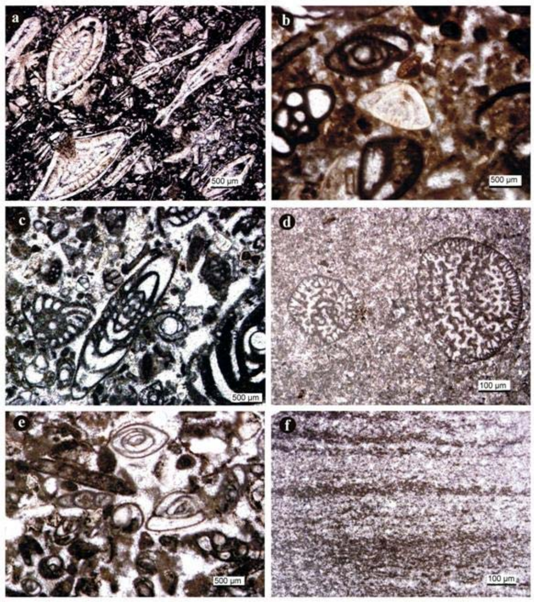


Fig. 6. Microfacies of the Jahrum Formation at Kuh-e Kurdeh section in Lar area. (a) Biofacies B, Lens-shaped nummulitids bioclastic wackestone- packstone. (b) Biofacies C, Foraminifera (perforate and imperforate) bioclastic wackestone-packstone. (c) Biofacies D, High diversity imperforate foraminifera packsotne-grainstone. (d) Biofacies E, *Dictyoconus Coskinolina* wackestone-packstone. (e) Biofacies F, Miliolids packstone. (f); Biofacies G, Stromatolitic boundstone.

The presence of large and flat foraminifera such as nummlitidae, in comparison with analogues in the modern platform [23-27], allowed us to interpret this facies as having been deposited in the lower photic zone.

4.2. Biofacies B. Lens-shaped nummulitids bioclastic wackestone-packstone

This biofacies (Figs. 5b, 6a) has a high diversity of benthic biota including large benthic forminifera and echinoid. The larger foraminifera consists of small-lens shaped *Nummulites*, *Operculina* and *Amphistegina*. Fragmentation of larger foraminifera is common and they are distributed irregularly among the larger foraminifera. Nummulutids with robust and small size tests are abundant biogenic components in biofacies B. Depositional textures are represented by wackestone- packstone. Peloids are also present.

The change in shape of test of larger perforate foraminifera with depth has been documented in the Cenozoic carbonate successions [28-32]. Prolification of perforates benthic foraminifera is indicative of normal marine conditions [28]. The sediments with robust and lens specimens reflect shallower water than those containing larger and flat nummulitids and discocyclinids [29, 31]. The relatively high degree of fragmentation of the larger foraminifera indicate moderate turbulence conditions for this facies.

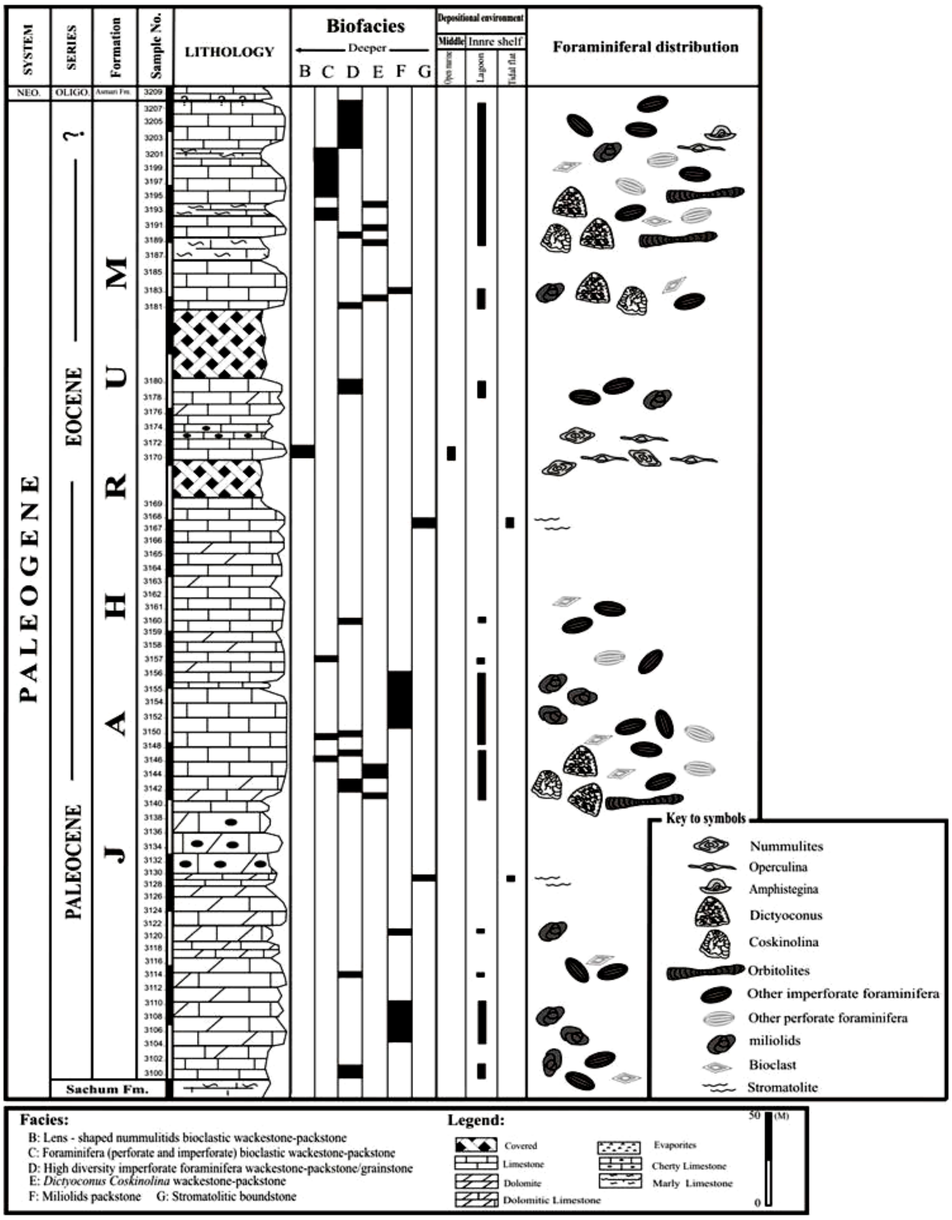


Fig. 7. Vertical facies distribution and biofacies of the Jahrum Formation at Kuh-e Gach section in Lar area, Zagros Basin

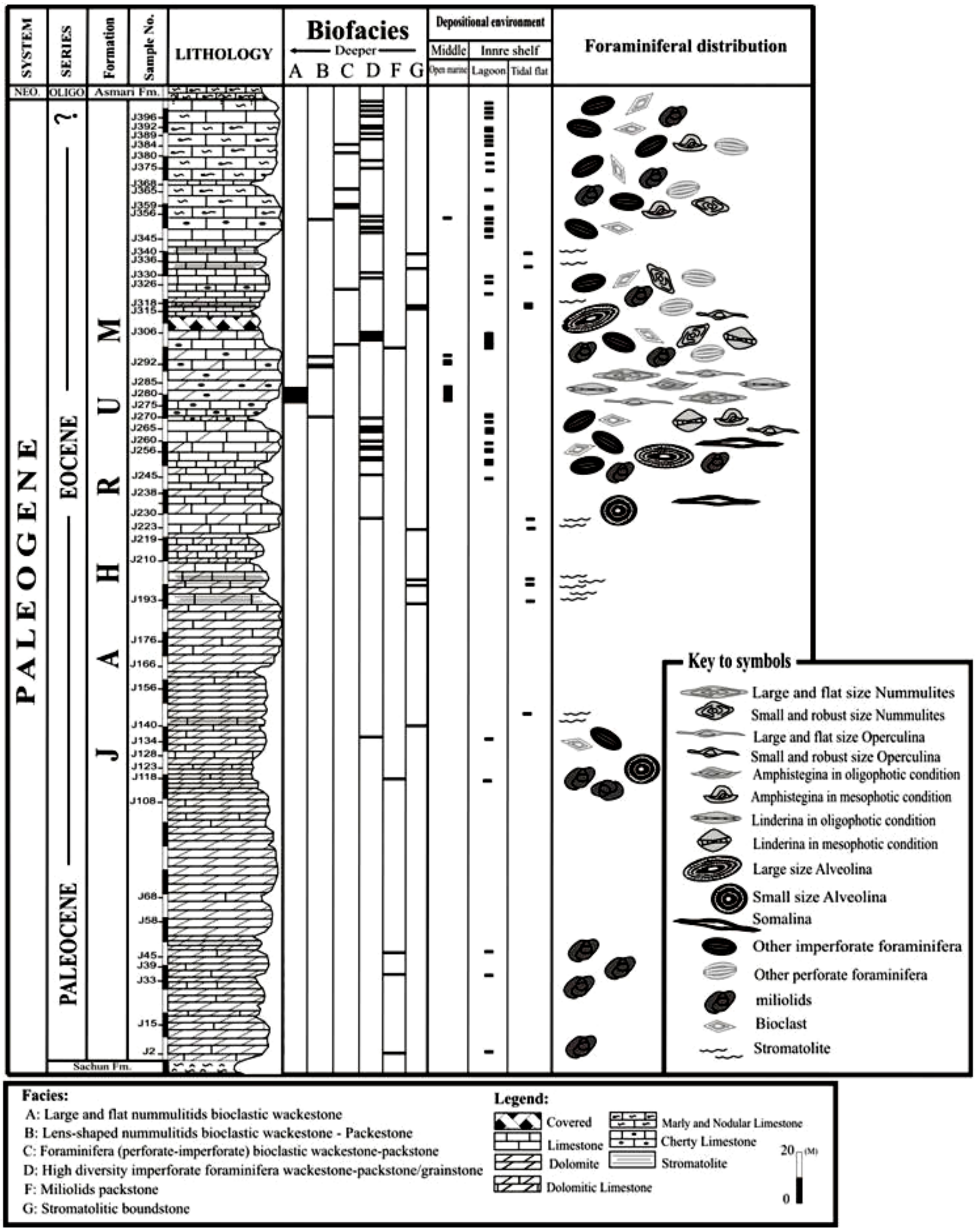


Fig. 8. Vertical facies distribution and biofacies of the Jahrum Formation at Kuh-e Kurdeh section in Lar area, Zagros Basin

4.3. Biofaces C. Foraminifera (perforate and imperforate) bioclastic wackestone-packstone

The main components of this biofacies (Figs. 5c, 6b) are benthic foraminifera, fragments of macrofossils and peloids. Both hyaline and imperforate foraminifera are present. Hyaline foraminifera are represented by small lens shaped *Nummulites*, *Linderina*, *Amphistegina*, *Operculina*, *Orbitolites*, and *Spherogypsina*, whereas among imperforate forms, miliolids, textularids, *Austrotrillina*, *Archias*, *Peneroplis* and *Orbitolites* are common. Echinoderms, gastropods and dasycldacean are also present. The features of biota and stratigraphic position of biofacies C indicate that sedimentation took place in the semirestricted lagoonal area. Co-occurrence of normal marine perforates foraminifera and platform–interior imperforates foraminifera suggest that there was no effective barrier present to separate the platform interior from the open marine [28, 33]. Nebelsick et al. [34], Corda and Brandano [35] and Vaziri-Moghaddam et al. [36]considered the similar facies as representative of a shelf lagoon.

4.4. Biofacies D. High diversity imperforate foraminifera wackestone-packstone grainstone

The abundant components of this biofacies are benthic foraminifers with imperforated walls such as: *Orbitolites, Somalina, Dictyoconus, Rhapydionina, Alveolina,* textularids and miliolids (Figs. 5d and 6c). These deposits include different textures ranging from wackestone to packstone and grainstone. Peloids are also present. In some samples, a subordinate amount of dasycladacean are also present.

The occurrence of a large number of imperforate foraminifera tests indicates that the sedimentation took place in a shelf lagoon setting with relatively low to moderate current energy [28, 33].

4.5. Biofacies E. Dictyoconus Coskinolina wackestone-packstone

This facies is dominated by benthic foraminifera (mainly *Dictyoconus* and *Coskinolina*) and other bioclasts (Fig. 6d). Small Peloids are also present. Textures reflect poorly sorted wackestone-packstone. Some of the grains have been partially micritized.

Both the fossil content and the sediment texture suggest a low-energy shallow subtidal environment. The features of component and stratigraphic position indicate that sedimentation took place in the lagoonal area.

4.6. Biofacies F. Miliolids packstone-grainstone

This biofacies is dominated by the occurrence of small miliolids and Peloids. Rare echinids fragments are also present (Figs. 5e and 6e).

This facies was deposited in very restricted innermost shelf areas. The abundance of peloids, miliolids and low diversity of fauna support this interpretation.

4.7. Biofacies G. Stromatolitic boundstone

These deposits are represented by a mud-supported texture formed by millimeter thick lamina, generally without fossils, irregularly undulating and laterally continuous (stromatolitic type cryptoalgal laminae) (Figs. 5f and 6f). The cyanobacteria with their filamentous features trapping and binding the sedimentary particles produced a laminated sediment or stromatolite.

This facies was deposited in a tidal flat environment [37-41]. Modern stromatolites are most common in shallow, intertidal and supratidal zones, although they may occur under subtidal conditions[42].

5. Sedimentary model

On the basis of biofacies variation, a sedimentary model can be proposed for the Jahrum Formation, suggesting that it was accumulated in an open shelf carbonate platform (Fig. 9). As a result of the facies interpretations and palaeoecology of larger foraminifera, it can be stated that middle shelf and higher portions of the inner shelf environments are present among the studied area. Planktonic foraminifera are absent in the studied sections, because the setting is located in shallow tropical sea environments, not-suitable for their accumulation.

In the study areas, the inner shelf deposits consist of an open lagoon, protected lagoon and tidal flat. Tidal flat facies is characterized by stromatolite boundstone. The wavy or flat-laminated stromatolite boundstones are formed by trapping and binding fine-grained carbonate sediments by cyanobacteria in the upper intertidal zone.

In the protected lagoon, the most abundant biofacies are medium to coarse grained larger foraminifera with imperforate wall-bioclast wackestone-packstone The presence of imperforate foraminifera that include *Archaias, Peneroplis, Dendritina, Alveolina, Austrotrillina, Orbitolites, Dictyoconus, Coskinolina* and miliolids indicates a low-energy, upper photic, shallow shelf lagoon depositional environment. Generally the upper photic zone is dominated by porcellaneus larger foraminifera, predominantly living in symbiosis with dinophyceans, chlorophyceans or rhodophyceans [33]. Open lagoon shallow subtidal environments are characterized by biofacies types that include mixed open marine bioclasts (such as echinoids and perforate foraminifera) and protected environment fauna (such as imperforate foraminifera). The diversity association of skeletal components represents a shallow subtidal environment, with optimal conditions with regard to salinity and water circulation.

Nummulitids with robust and small size tests are abundant fauna in the upper middle shelf environments. The sediments with robust and lens specimens reflect shallower water than those containing larger and flat nummulitids and discocyclinids [29, 31]. The change in shape of test of the larger perforate foraminifera with depth has been documented in the Cenozoic carbonate successions [28-32]. The relatively high degree of fragmentation of the larger foraminifera points to moderate turbulence conditions for this facies. Lower middle shelf facies are differentiated from upper middle shelf by the greater amount of micritic matrix, an increase in the flatness, and size of the perforate foraminifera.

6. Palaeoecology

Larger foraminifera are important constituents of shallow-water carbonates from the Early Eocene to Early Miocene of SW Iran (Zagros Basin). Larger foraminifera which occupied most niches in the photic zone of tropical to subtropical oceans in the Tethyan realm during the Paleogene, provide a useful tool for reconstructing palaeoenvironments and biostratigraphy.

Scheibner et al. [43] proposed that the larger foraminifera turn over (LFT) during the Palaeocene-Eocene transition closely linked with the Paleocene-Eocene thermal maximum (PETM). Larger foraminifera are extreme K-strategists, flourishing in a constant, typically oligotrophic environment [44].

Carbonate production directly or indirectly depends on photosynthesis and consequently on light penetration into water column. The Jahrum Formation contains both larger benthic imperforate foraminifera and, subordinately hyaline foraminifera. Both groups of larger foraminiferal are often supported by endosymbiotic relationships with unicellular algae.

The paleoenvironmental distribution of foraminiferal assemblages and depositional conditions have been reconstructed, based on the depth range of recent foraminifera, foraminifera-bearing Early Oligocene carbonates from the Lower Inn Valley of Austria [34], Oligo-Miocene foraminiferal limestones of the Zagros Basin [36, 45, 46], Eocene foraminifera limestones of the Adriatic carbonate platform [22], Paleocene-earliest Eocene larger benthic foraminifera of SW Slovenia [47], benthic carbonate assemblages across the Paleocene-Eocene boundary of the Campo section [48] and Early Eocene foraminiferal limestones of the Pyrenees [49]. The occurrence of a large number of porcelaneous imperforate foraminiferal tests may point to the depositional environment being slightly hypersaline. The biotic assemblage indicate a deposition within the photic zone, in a seagrass-dominated environment, as suggested by the presence of epiphytic porcellaneous foraminifera (*Alveolina*, *Archaias*, *Peneroplis*), such an assemblage has been interpreted as a shelf–lagoon environment [50, 37, 51, 36].

Perforate foraminifera that exist in shallow water are characterized by hyaline walls and they protect themselves from UV light by producing very thick, lamellate test walls to avoid photo inhibition of symbiotic algae within the test in bright sunlight, and/or test damage in turbulent water or they occur in moderately deeper water. Flatter tests and thinner test walls with increasing water depth reflect decreased light levels at greater depths or possibly poor water transparency in shallow water [29].

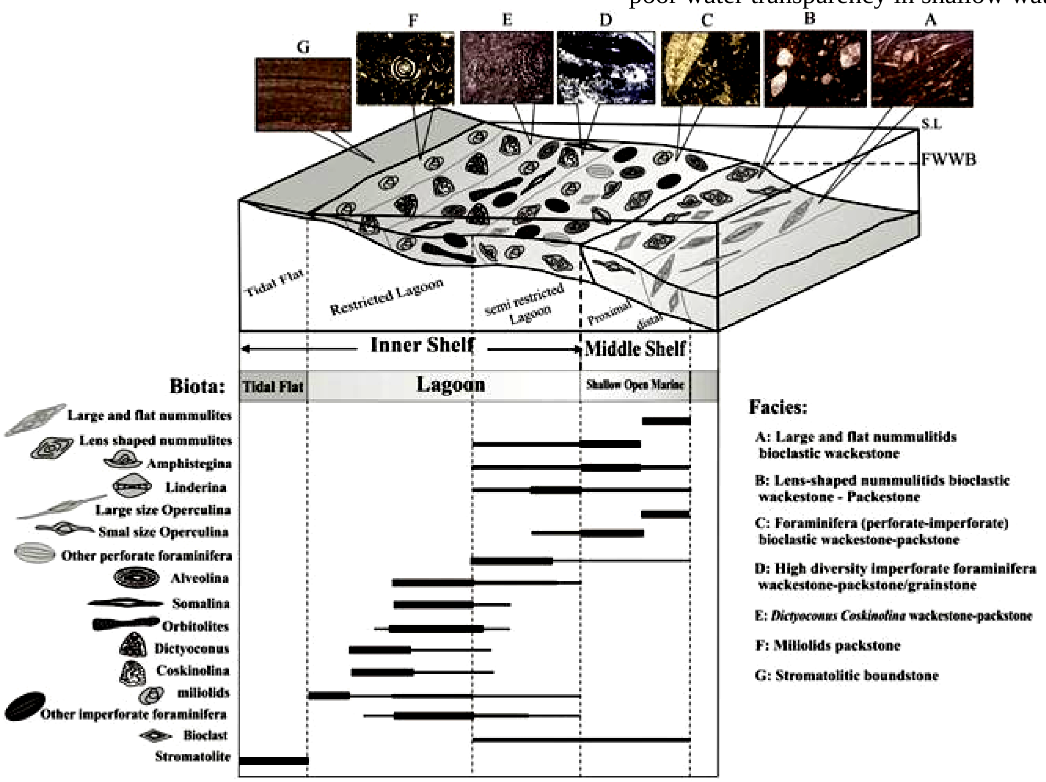


Fig. 9. Depositional model for the platform carbonates of the Jahrum Formation at the studied sections

7. Skeletal grain association

The differentiation between non-tropical and tropical carbonates is mainly based on analysis of skeletal components [52-54]. Non-tropical carbonates are identified by the absence of certain skeletal and non-skeletal grains (e.g. *Halimeda*, ooids) and framework-forming zooxanthellate corals [55]. Non-tropical carbonates are subdivided into warm-temperate and cool-temperate provinces [56]. Tropical associations are restricted to the tropics, whereas sediments of temperate latitudes also extend into the tropics [52- 54, 57]. Lees and Buller [52], Lees [56], Carannante et al. [53] and Hallock and Schlager [58] have concluded that parameters such as depth, nutrients and salinity additionally influence distribution of skeletal grains.

Consequently, certain skeletal grains may exist in various environments. James [55] introduced two new terms for carbonate grain associations ('Photozoan' and 'Heterozoan') that are applicable to the entire Phanerozoic. The cool water sediments are always heterozoan, however, the heterozoan association does not mean that the carbonates are cool water [55].

The most common skeletal components in limestones of the study areas are large benthic foraminifera, whereas echinoids, bryozoans and bivalve components are less common (Fig. 10). Corals are almost absent. The biotic associations and palaeolatitudinal reconstructions [59] suggest that carbonate sedimentation of the Jahrum Formation took place in tropical waters under oligotrophic conditions and is dominated by a heterozoan skeletal assemblage.

Zooaxanthellate corals did not make framework structures in the lower latitudes due to worldwide warm sea-surface temperatures and enhanced CO_2 levels [48]. Unlike zooaxanthellate corals, increasing summer sea-surface temperatures do not cause symbiont loss in larger foraminifera [60]. Larger foraminifera and their symbionts algae appear to be less succeptible to high summer temperatures [61]. Therefore, the extension of heterozoan assemblages in the Jahrum Formation related to the palaeoecology of zooaxanthellate corals**.**

8. Conclusions

Biogenic components of the Jahrum Formation are dominated by benthic foraminifera. Based on biogenic components and textures, 8 biofacies have been recognized and grouped into two depositional environments that correspond to the inner and middle shelf environments, and are interpreted as a carbonate platform developed in an open shelf settings. As a result of the facies interpretations and palaeoecology of larger foraminifera, it can be stated that middle shelf and higher portions of the inner shelf environments are present among the studied areas. The biotic assemblages of the Jahrum Formation suggest that carbonate sedimentation took place in subtropical waters with oligotrophic conditions.

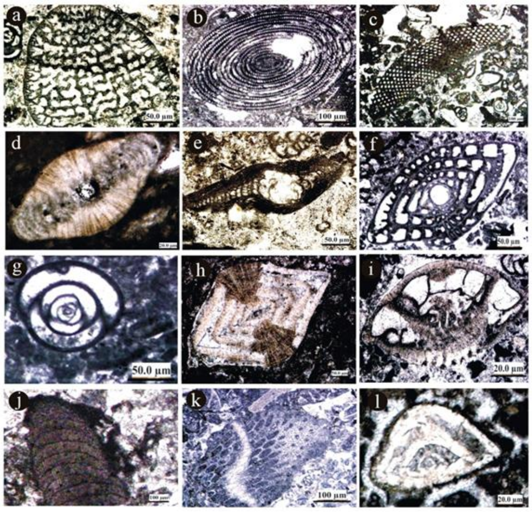


Fig. 10. (a) *Dictyoconus indicus,* (J330). (b) *Alveolina rutimeyeri,* (J303). (c) *Orbitolites* sp., (J374), (d) *Linderina brugesi,* (J278). (e) *Somalina stefaninii,* (J256) (f) *Penarchaias glynnjonesi*(3203) (g) *Pyrgo* sp. (3146) (h) *Nummulites* sp., (J274) (i) *Medocia blayensis* (3199). (J) Corallinacean fragment, (J270). (k) Bryozoan fragment (J275). (l) *Amphistegina* sp. (3202)

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