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Biofacies Analysis of the Upper Oligocene Deposits (Qom Formation) in Urumieh Dokhtar Zone, Iran

Análise de Biofácies dos Depósitos do Oligoceno Superior (Formação Qom) na Zona Urumleh Dokhtar, Irã

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Reebido em: 04/05/2017 Aprovado em: 27/06/2017
DOI: http://dx.doi.org/10.11137/2017_2_163_179

Abstract

In order to determine the accurate paleoenvironmental conditions of Qom Formation, one stratigraphic section was studied in the Urumieh-Dokhtar Zone (West of Ashtian). 60 thin sections of the Qom Formation, 71 m thick, were prepared and the distribution of benthic foraminifera was analyzed. On the basis of the recognized foraminifera, the age of Qom Formation in the studied section is assigned to the Late Oligocene (Chattian). In this study, sex different biofacies and two lithofacies types have been recognized, that can be grouped into two depositional environments, back ramp (alluvium channel, lagoon and shoal) and the ramp (inner, middle and outer ramp). The alluvium channel is characterized by Gms (gravel with massive layering and abundant matrix). The shoal is represented by fine to medium sandstone: calcite cemented submature litharenite. The lagoon is dominated by the presence of bioclastic bryozoan corallinacea wackestone- packstone and bioclastic foraminifera corallinacean wackstone to packstone. The inner ramp is characterized by bioclastic benthic foraminifera (perforate and imperforate) wackestone-packstone and the middle ramp represented by bioclastic perforate foraminifera wackstone-packstone and bioclastic *Operculina* packstone. Outer ramp is characterized by bioclast benthic and planktonic foraminifera mudstone.
Keywords: Qom Formation; Miocene; Paleoenvironment; Ramp; Urumieh Dokhtar; Iran

Resumo

De modo a determinar as condições paleoambientais da Formação Qom, uma seção estatigráfica foi estudada na Zona Urumieh-Dokhtar (Oeste de Ashtian). Seções de 60 m de espessura da Formação Qom (a qual possui 71 m de espessura) foram preparadas e a distribuição de foraminíferos bentônicos foi analisada. Com base nos foraminíferos reconhecidos, a idade da Formação Qom foi estimada em Oligoceno Final (Chattiano). Neste estudo, seis diferentes biofácies e duas litofácies foram reconhecidas, sendo agrupadas em dois ambientes deposicionais: fundo de rampa (canal aluvial, laguna e bancos arenosos) e rampa (proximal, media e distal). O canal aluvial é caracterizado pela litofácies Gms (cascalho matriz-suportado). Os bancos arenosos são representados por arenito médio a fino: litarenito submaduro cimentado por calcita. A laguna é dominada pela presença de wackestone- contendo bioclastos de corais e briozoários e por wackstone-packstone com bioclastos de corais e foraminíferos. A rampa proximal é caracterizada por *wackestone-packstone* contendo bioclastos de foraminíferos bentônicos (perforados e imperforados), enquanto a rampa média é representada por *wackestone-packstone* contendo bioclastos de foraminíferos perforados e *packstone* contendo bioclastos de *Operculina*. A rampa distal é caracterizada por argilitos contendo bioclastos de foraminíferos bentônicos e planctônicos.
Palavras-chave: Formação Qom; Mioceno; Paleoambiente; Rampa; Urumieh Dokhtar; Irã

1 Introduction

The Qom Formation is one of the oil reservoirs in Iran and spreads through Central Iran (back arc basin), Urumieh-Dokhtar (Intra arc ban) and Sanandaj-Sirjan (forearc basin) Zones. Loftus (1855) introduced the Qom Formation as Nummulitic series with Oligocene age. Furrer & Suder (1955) divided the Qom Formation into a-f Members and introduced the mountains surrounding of Qom city as type locality. Later, Abaie *et al.* (1964) divided the c Member of Qom Formation into four Sub-Members (c1-c4). Moreover, Bozorgnia (1966) added an Unnamed Member to the base of Qom Formation in the Kashan area.

Mostly all of the previous works on the Qom Formation are limited to the middle parts of Iran, as the formal lithostratigraphic subdivisions of Qom Formation are limited to the Central Iran. However, surprisingly little information is available concerning the different biostratigraphical and paleoenvironmentical properties of the Qom Formation in the Urumieh–Dokhtar. It is essential and important to study different properties of the oil-bearing Qom Formation because of economic importance in the Iranian Plate at the same time (Mohammadi *et al.*, 2011, 2013).

This paper examines in detail the biofacies of Qom Formation in the Ashtian area, Urumieh Dokhtar Zone, and provides palaeoenvironmental interpretations of the sedimentary succession.

2 Materials and Methods

As shown in Figure 1A, the study area is located about 3 km west of Ashtian City. The geographic coordinates of the study section are 49º 59' E, 34º 31' N.

The total thickness of Qom Formation is 70 m in the Ashtian section. 60 samples were collected bed by bed. Thin sections were provided for harder litologies whilst softer litologies were disaggregated and the foraminifera picked and analyzed. The samples disaggregated by soaking in water for several days and then washed through 200, 120, 63 and 36 mm sieve series with tap water. Sediment infilling of foraminiferal tests was removed by repeated sonic agitation of the residues for about 15 minutes. The best-preserved specimens of planktonic foraminiferal were picked and mounted on micro slides for permanent record and taking SEM microphotographs.

All rock samples and thin sections have been housed in the Department of Geology, Lorestan University. Definition of microfacies is based on depositional texture, grain composition and fossil content. The classification of carbonate rocks followed the nomenclature of Dunham (1962) and Flügel (2010).

Biogenic components of the Qom Formation consist of different biota including: large benthic and small planktonic foraminifera, red algae, bryozoans, bivalves, echinoderms and gastropoda. The fauna association, particularly the foraminifera, is used for the paleoenvironmental and biostratigraphical interpretation, since they are excellent bio-indicators for age dating and the paleoenvironmental interpretation. Larger benthic foraminifera developed complicated internal structures which can be identified when they are randomly thin sectioned. Beavington-Penny & Racey (2004) showed that because of rapid diversification of foraminifera, these organisms can provide complete and detailed evidence for biostratigraphic analysis of the shelf limestone. There is no formal biozonation for the Qom Formation. However, conspicuous similarity is observed between the foraminiferal assemblages of Qom Formation and Asmari Formation (Zagros region, SW Iran). Therefore, Daneshian & Ramezani Dana (2007); Mohammadi *et al.* (2011) used the Asmri Formation biozonation in order to determinate the Qom Formation age.

In addition to their biostratigraphic utility, foraminifera are also extremely useful in determining the environment of deposition. They are photosymbiontic organisms (Reiss & Hottinger, 1984) and they require light, which requires that they live in a photic zone. Changes in foraminiferal assemblages can indicate fluctuations in light level, and this gives valuable information for the interpretation of palaeoenvironments and paleobathymetry (Hallock & Glenn, 1986). Paleobathymetry itself controls other environmentally important factors such as temperature, oxygenation, substrate type, etc. The size and shape of larger foraminifera gives important clues to environment of deposition, especially paleobathymetry. Work by Amirshahkarami & Karvan (2015), Amirshahkarami *et al.* (2007), Nouradini *et al.* (2015), Sadeghi *et al.* (2009) and Sooltanian & Seyrafian (2011) has shown that by shape and size to foraminifera distributions, differing genera of larger foraminifera have differing environmental niches that can be extrapolated into fossil record of the Oligo-Miocene deposits in Iran.

3 Geological Setting and Stratigraphy

Based on the sedimentary sequence, magmatism, metameorphism, structural setting and intensity of deformation, Heydari *et al.* (2003) subdivided the Iranian Plateau into ten Provinces, including Zagros (Khuzestan plain, Simply Folded Belt, and Thrust Zone), Sanandaj- Syrjan, Urumieh-Dokhtar, Central Iran, Alborz, Kopeh-Dagh, Lut, and Makran (Figure 1B). Mohammadi *et al.* (2010) and Reuter *et al.* (2009) reported that the Qom Formation is the last transgression of the sea in the Sanandaj-Sirjan (fore-arc), Urumieh-Dokhtar magmatic arc (Intra-arc), and Central Iran (back-arc) basins. The study section is located in the Urumieh- Dokhtar Basin.

The thickness of Qom Formation in west of Ashtian is 71 m and consists of conglomerate, sandstone, limestone and marl. Based on the lithologic characteristics of these deposits and their stratigraphic relations, five lithostatigraphic units were recognized. The Qom Formation in the studied section is transitionally overlies the Oligocene Lower Red Formation. The contact with the Middle Miocene Upper Red Formation is conformable (Figure 2).

In terms of local foraminiferal zonations applied to the Zagros foreland basin, the interval from base to top of section belongs to Assemblage Zone 56 of Wynd (1965) and to Assemblages Zone

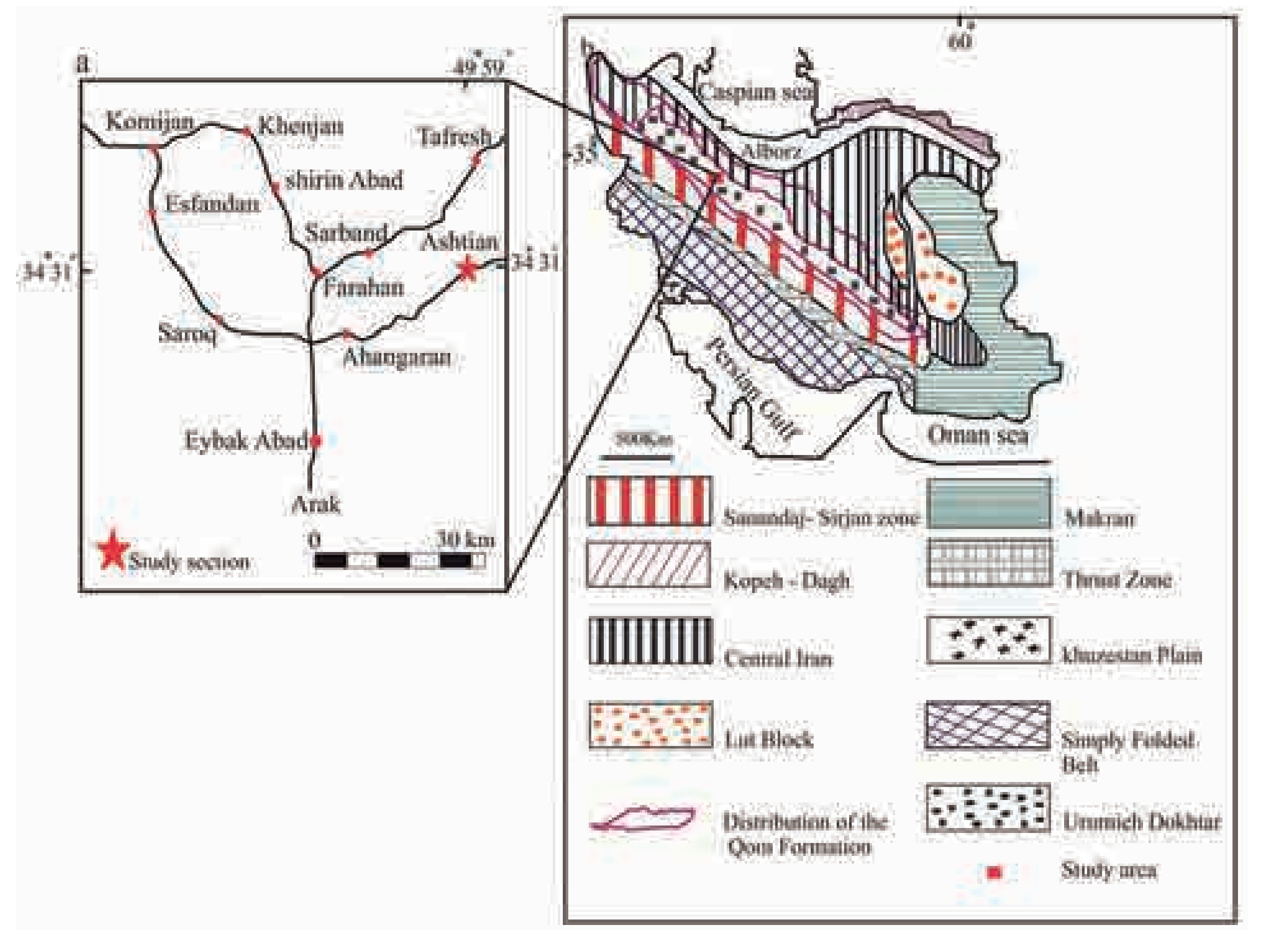

Figure 1 (A) Location of studied section; (B) Geological subdivisions of Iran (adapted from Heydari *et al.*, 2003) and the distribution map of Qom Formation in Iran.

3 of Adams and Bourgeois (1967; Figure 3). Among the identified larger foraminifera, *Globigerina ouachitaensis* and *Spiroclypeus* sp. are the marker species. The age of First and last occurrence of *Globigerina ouachitaensis*, and *Spiroclypeus* sp. were determined by Mosadegh *et al.* (2009) and Ehrenberg *et al.* (2007) by the strontium isotope stratigraphy method. The strontium data indicate that the first and last occurrences of both foraminifers are Chattian in Iseh and Dezful Embayment (Zagros Basin), respectively. Based on these microfauna, the outcrop of the Qom Formation at this section can be dated as Late Oligocene (Chattian) in age (Figure 3).

The most diagnostic foraminifera and non-foraminifera in the studied section are shown at figures 4 and 5.

4 Paleoecology

The foraminifera and algal taxa within Qom Formation are extremely useful in determining the environment of the studied depositional levels. This is particularly true with respect to depth, which itself controls other environmentally important factors such as hydrodynamic energy, nutrient supply, light penetration and temperature.

As stated by Beavingtone-Penney & Racey (2004), the shape of benthic foraminifera reflects their incompatibility in high or low energy environments and their symbiotic relationship with algae. High-energy conditions and increasing water motion causes the test of larger foraminifera to be thick and decreases its growth rate and eventually reduces their test size.

Morphology of *Operculina* is a clue to Paleobathymetry. As shown in figure 6, Reiss & Hottinger (1984) observed that the test of *Operculina* showed increasing compression or flattening, as water depth increases in the Gulf of Aqaba, Red Sea, The strongly compressed (flattened) forms illustrated here probably indicate water depth of 50-100 mbsl.

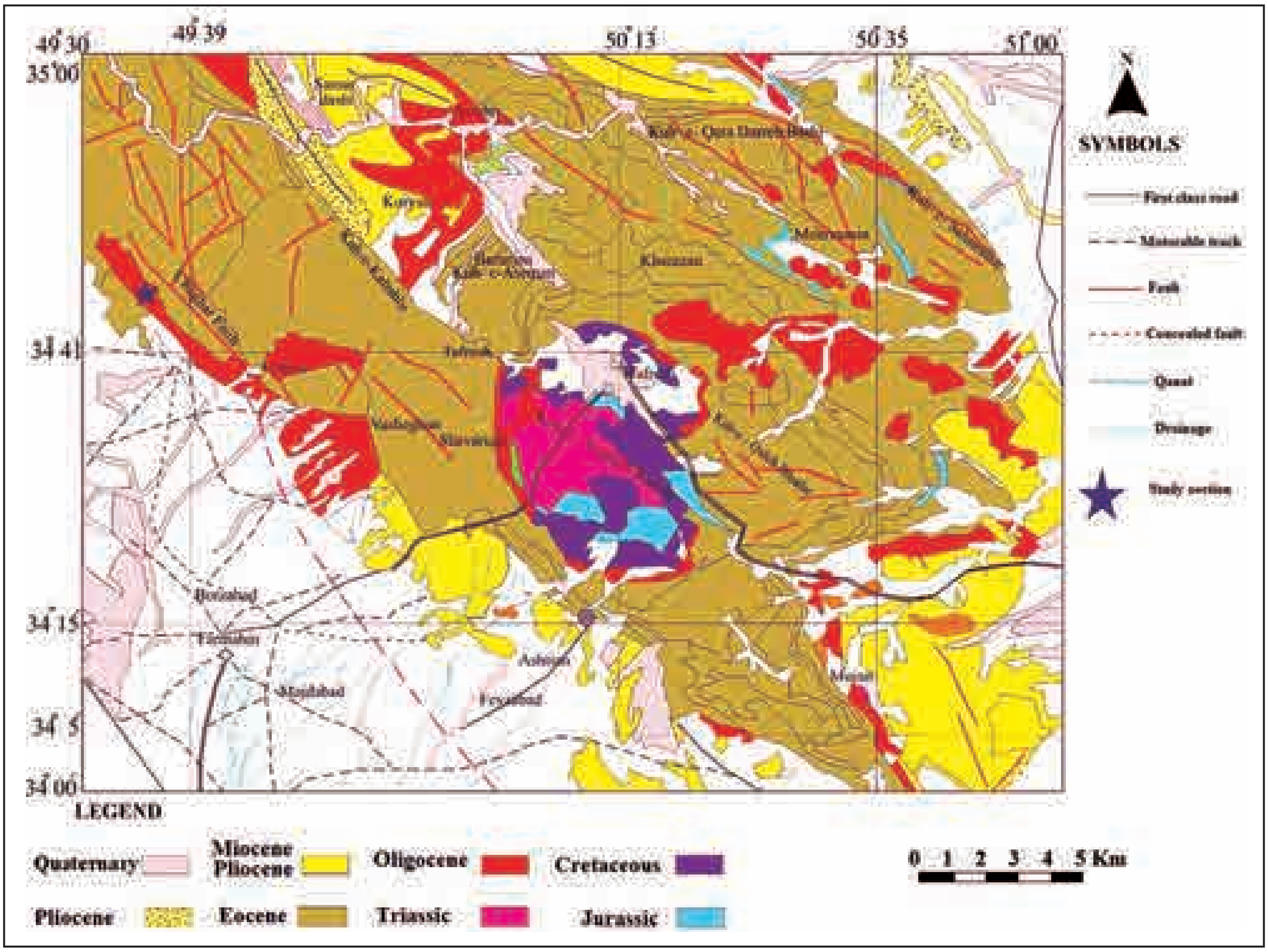

Figure 2 Simplified geological map of Ashtian (adapted from Emami, 1991).

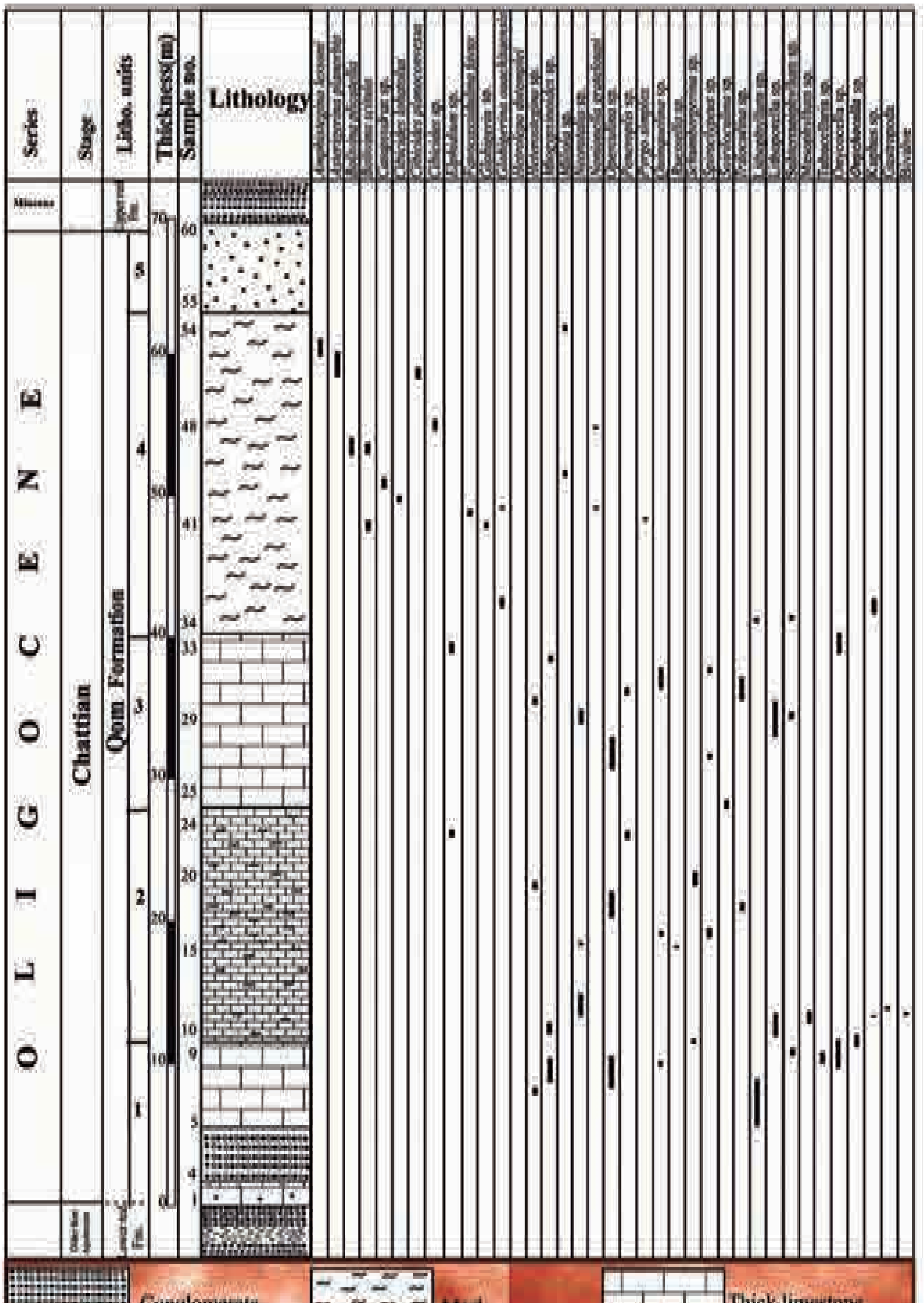

Figure 3 Vertical distribution of foraminifera and non-foraminifera of the Qom Formation at the studied section.

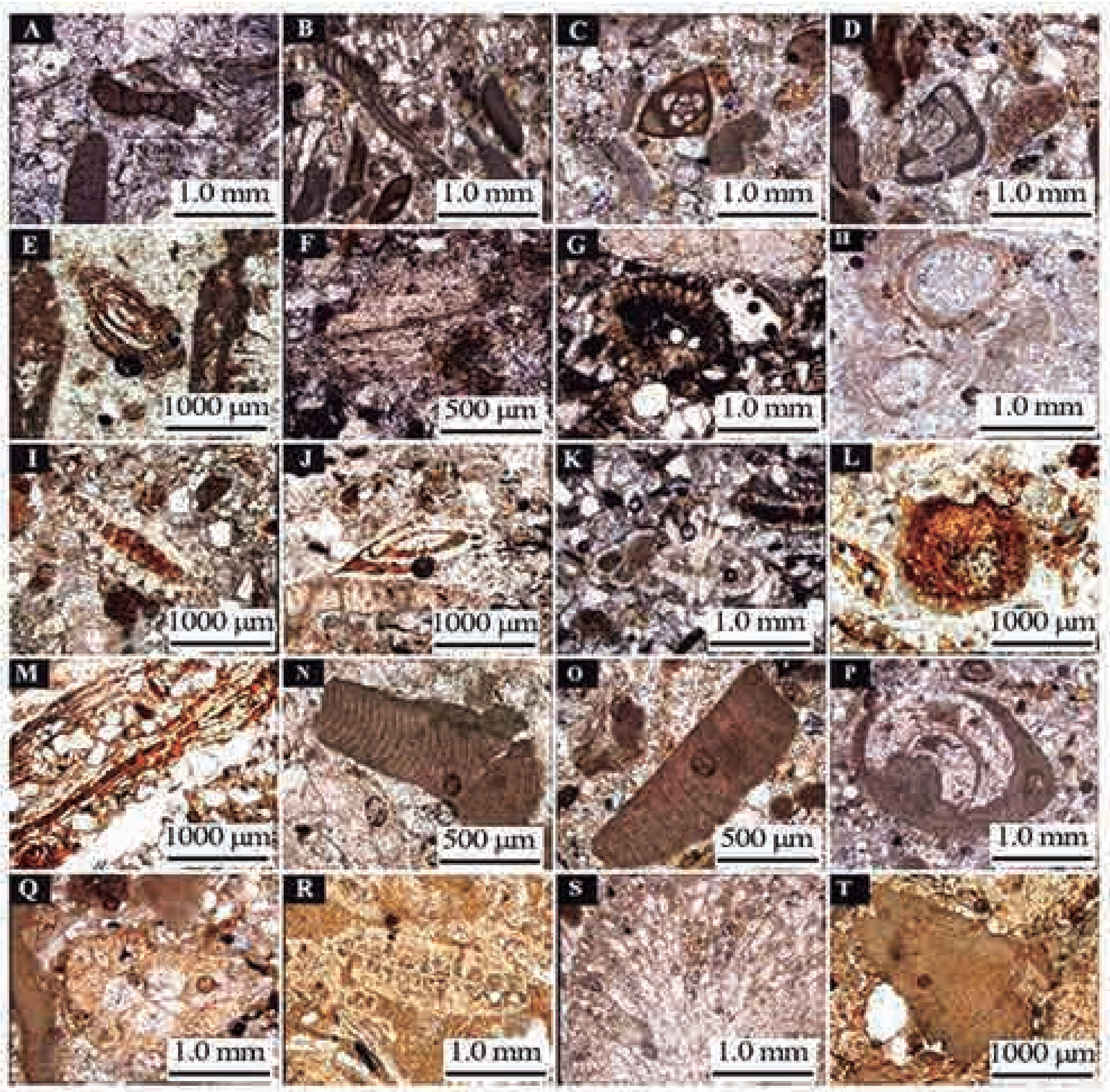

Figure 4 (A) *Spiroloculina* sp., sample no. 4; (B) *Peneroplis* sp., sample no. 4; (C) *Quinqueloculina* sp., sample no. 4; (D) *Triloculina* sp., sample no. 3; (E) *Schlumbergerina* sp., sample no. 4; (F) *Spiroclypeus* sp., sample no. 3; (G) *Elphidium* sp. 14., sample no. 24; (H) *Kuphus* sp., sample no. 68; (I) *Miogypsinoides* sp., sample no. 27; (J) *Amphistegina lessonii*, sample no. 35; (K) *Neorotalia* sp., sample no. 27; (L) *Sphaerogypsina* sp., sample no. 30; (M) *Heterostegina* sp., sample no. 30; (N) *Subterraniphyllum* sp. sample no. 8; (O) *Lithophyllum* sp., sample no. 8; (P) *Lithoporella* sp., sample no. 7; (Q) *Tubucellaria* sp., sample no. 9; (R) *Cellepora* sp., sample no. 8; (S) *Onychocella* sp. sample no. 8; (T) *Lithothamnium* sp., sample no. 9.

The flattening of tests with increasing water depth is a strategy employed by a number of modern and fossil larger foraminifera, presumably due to a large and vast surface area that allows the photosynthetic symbionts to exist as light penetration in sea water decreases with depth. They also need to protect themselves from very high degrees of illumination causing damage by ultraviolet light. Nummulitids with transparent and hyaline walls protect themselves in deeper water from UV-light by producing large and flat walls (Rasser *et al.*, 2005).

Larger benthic foraminifera are oligotrophic to mesotrophic biota have adapted to nutrient-deficient conditions and are extreme K-strategists, characterized by slow growth, late maturity (Renema, 2006), but they cannot respond competitively

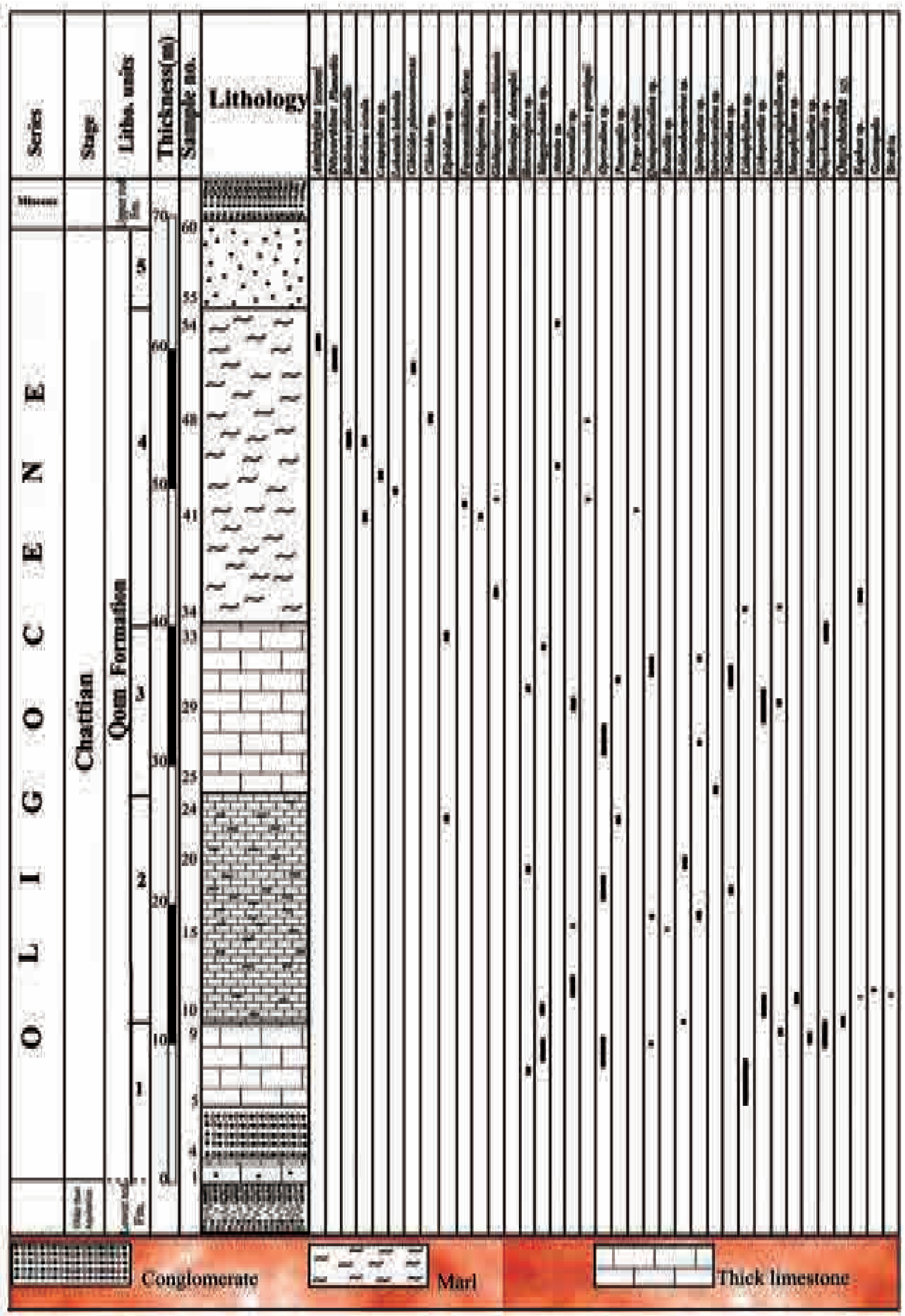

Figure 5 (A) *Favocassidulina favus*, sample no. 42; (B) *Discorbina planorbis*, sample no. 51; (C) *Amphistegina lesson*ii, sample no. 54; (D) *Nonionoides grateloupii,* sample no. 42; (E) *Lobatula lobatula,* sample no. 42; (F) *Cibicides planoconvexus*, sample no. 52; (G) *Pyrgo simplex* sample no. 41; (H) *Bolivina plicatella*, sample no. 46; (I) *Reusella* sp., sample no. 45, (J) *Globigerina ouachitaensis*, (Face ombilicale) sample no. 35; (K) *Globigerina ouachitaensis*; (Face spiral); (L) *Globigerina ouachitaensis* (Face axial).

when nutrient resources become abundant or eutrophic (Hallock, 1985). Nutrients material enters shallow-water communities principally by upwelling of deeper waters or by run-off from land (Hallock, 1999).

Larger benthic foraminifera acquire their nutrient requirement by algal symbionts. Symbioses are affected by the influences of light which this factor is controlled by depth, suspended material and nutrient supply. Symbiont-bearing large foraminifera are restricted to warm water of tropical realms. Brandano & Corda (2002) and Brandano *et al.* (2010) showed Larger benthic foraminifera would rather live in warm waters, with temperatures ranging between 18-20ºC.

The unit 1 of Qom Formation at Ashtian section contains of imperforate foraminifera (such as miliolids), red algae and bryozoans that are light-independent. Although miliolids may be found in a variety of very shallow, hyposaline to hypersaline environments, or even in abundance on fore-reef slopes (Seyrafian *et al.*, 2011) but as Geel (2000) showed, the occurrence of abundant imperforate foraminifera indicates the shallowest water depth of environment. Vaziri Moghaddam *et al.* (2010) reported imperforate foraminifera of the upper part of shallowest photic zone and in a seagrass-dominated environment, as suggested by the presence of epiphytic porcellaneous (*Peneroplis*) foraminifera at the Asmari Formation in Zagros Basin.

The presence of porcelaneous foraminifera and lack of hyaline wall structure foraminifera and other normal open marine fauna and low frequency of calcareous agglutinated foraminiferal and echinoid fragments indicate occurrence of the higher level of hyper-saline water. Miliolids become predominant skeletal occurring microfacies in hyper-saline environments (Mossadegh *et al.*, 2009).

There are only bryozoans and red algae in the upper part of unit 1 that maybe is related to eutrophy conditions by run-off from land.

Most important fauna at unit 2 are *Elphidium* and *Pyrgo*. Hallock & Glenn (1986) reported that an association of *Elphidium* and miliolid reflects water depth environment below 35 m that deposition took place in the inner shelf environment.

Abundant of large benthic hyaline foraminifera with red algae in the unit 3 (*Neorotalia, Miogypsinoides* and *Operculina*), represents deposition in an oligophotic to mesotrophic zone of a carbonate ramp under tropical to subtropical conditions (Pomar, 2001).

Morphology of *Operculina* in unit 3 (Figure 6) reflects the water depth environment between 50-100 mbsl. Beavington-Penney & Racey (2004) reported that flattened test shapes of *Operculina*, were deposited in the lower photic zone in the distal middle shelf. Seyrafian *et al.* (2011) stated that *Operculina complanata* are found in deepest part of photoc zone of the Oligocene- Miocene Asmari Formation in Zagros Basin.

The abundance of planktonic foraminifera and the absence of calcareous algae in unit 4 suggest that this unit was deposited below the photic zone. It is deepest part of Qom Formation in section study. Geel (2000) and Mossadegh *et al.* (2009) reported occurrence of planktonic foraminifera, small and large benthic foraminifera with hyaline wall structure reflect normal sea water conditions (34-40 psu).

5 Biofacies Analysis

As shown in Figures 7 and 8 (A-G), on the basis of the distribution of the skeletal components and facies relationships in the Oligocene succession in the studied area, 6 biofacies and 1 lithofacies have been identified. Among the most important facies, one might point out the following samples.

5.1 Biofacies A: Bioclast Benthic and Planktonic Foraminifera Mudstone

This biofacies occurs in unit 4 and is dominated by rhythmically alternating thin olive green to grey marl and represented by association of hyaline benthic and pelagic foraminifera, gastropoda and bivalvia with dominant mud-supported texture.

Interpretation: Absence of calcareous algae represents an aphotic zone (Cosovic *et al.*, 2004). The high amounts of micrite and lack of sedimentary structures reflect a relatively low turbulence environment suggest that this microfacies was deposited in calm, low energy hydrodynamic and deep normal salinity water (Scholle *et al.*, 1983). The

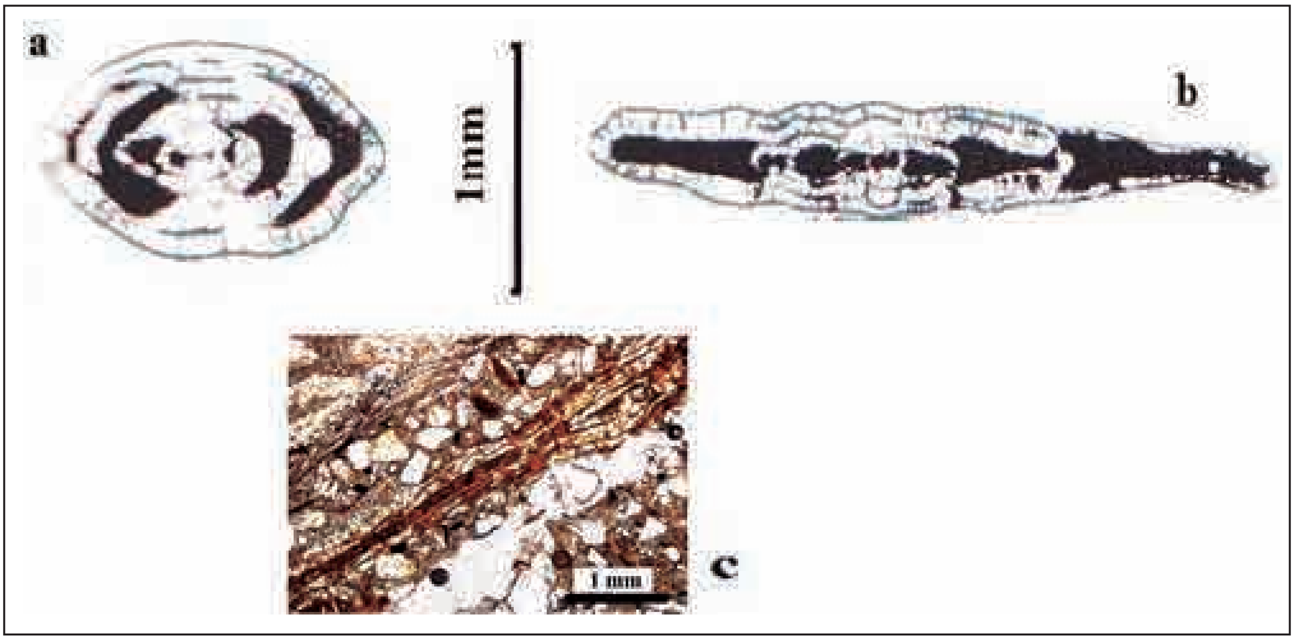

Figure 6 Variations in the morphology of *Operculina* with changing in water depth (after Reiss & Hottinger, 1984); (A) specimen is from ware depth of 20-50m in the modern Gulf of Aqabea; (B) specimen is from water depth of 50-100m; (C) *Operculina* sp. sample number 32.

precence of planktonic foraminifera accompanied by perforate foraminifera indicated an outer ramp depositional setting below storm wave base in the lower limit of the photic zone (Corda & Brandano, 2003; Romero *et al.*, 2002; Vaziri-Moghaddam *et al.*, 2006). Amin Rasouli (2005) reported a similar microfacies from the Qom Formation in south Central Iran and also Mohamdi *et al.* (2010) reported similar microfacies from Qom Formation in west of Saveh.

5.2 Biofacies B: Bioclastic *Operculina* Packstone (Figure 8A)

This facies occurs in upper part of unit 3. The main characteristic feature of this facies is the presence of large and flat epifauna benthic foraminifera *(Elphidium* sp., *Miogypsinoides* sp.). Nummulitidae (*Operculina, Hetrostegina*) with small size test (A form) are abundant biogenetic components in microfacies B. Other components of this facies include echinoids, gastropoda and bivalves. The matrix is fine-grained micrite. Fine medium grained detrital quartz is recognized in this microfacies. The Packstone is poorly medium sorted and grains are angular to subangular. Megascopically, this microfacies is composed of medium bedded green marly limestone.

Interpretation: Large rotaliids (such as *Amphistegina*) are in fact restricted to the photic zone, since all of them house symbiotic algae (Pomar, 2001) and diatoms (Mateu-Vicens *et al.*, 2009) that they are able to use a wide range of light wavelength. They can be found in a variety of palaeobathymetric setting even below depth 180 mbsl (Beavington-Penny & Racey, 2004).

Bassi *et al.* (2007) divided the photic zone into upper and lower parts; in this classification, *Neorotalia* live in the upper part of the upper photic zone, and *Heterostegina*, *Operculina* are dominant in the lower part of the photic zone.

A form dominated fossil communities are likely to have formed in the shallowest or deepest part of depth range. These two environments can be distinguished on the basis of the matrix and stratigraphic position (Beavington-Penny & Racey, 2004). The relatively low degree of fragmentation of the Nummulitidae indicates that these deposits formed in the distal part of the middle ramp, well below the fair-weather wave base since there are no signs of wave hydraulic turbulence in these microfacies. The abundance of large and flat epifauna benthic foraminifera (*Operculina* and *Amphistegina*) and quartz grains in micritic texture may indicate that the sedimentary environment was situated in

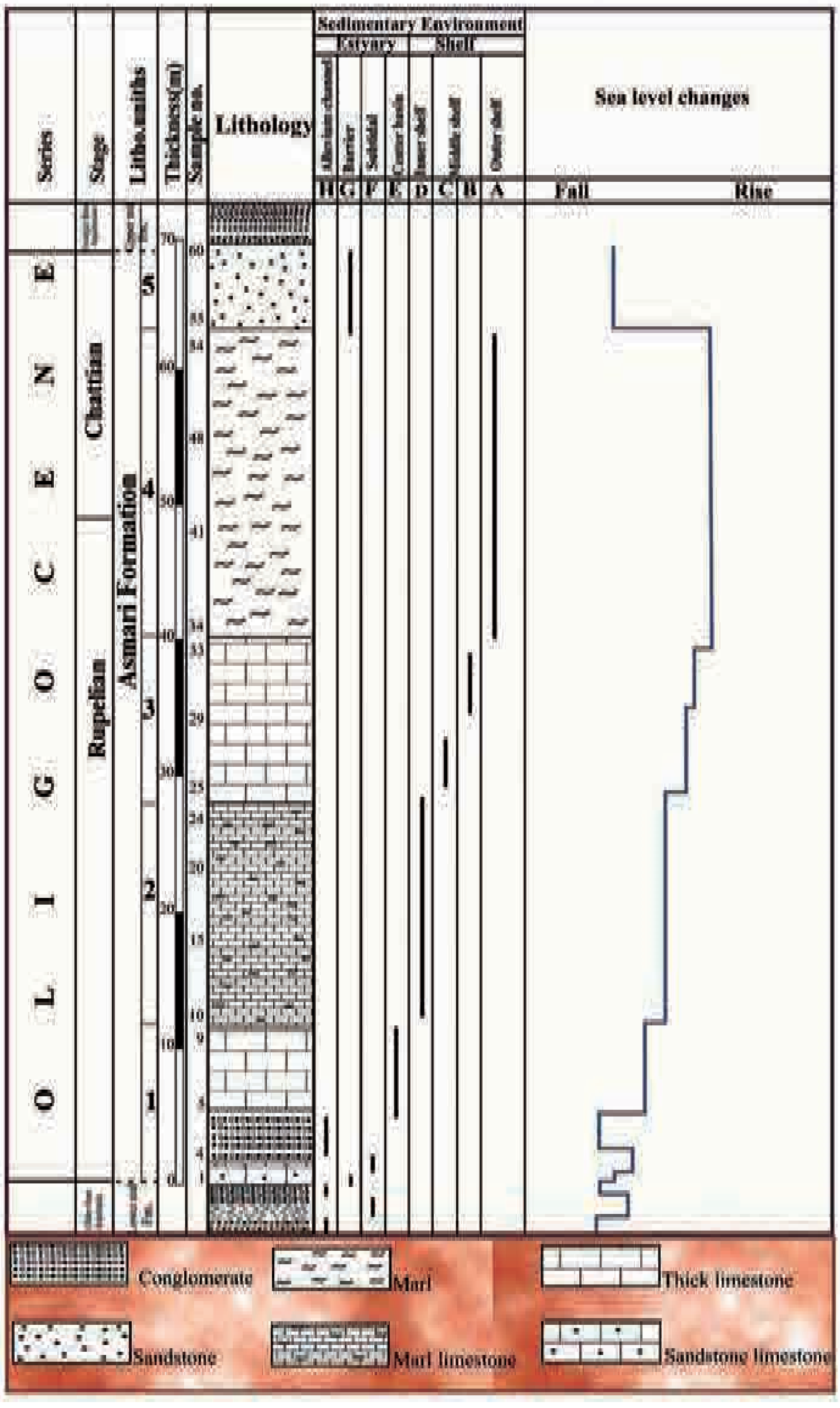

Figure 7 Vertical facies distribution of the Qom Formation at west of Ashtian.

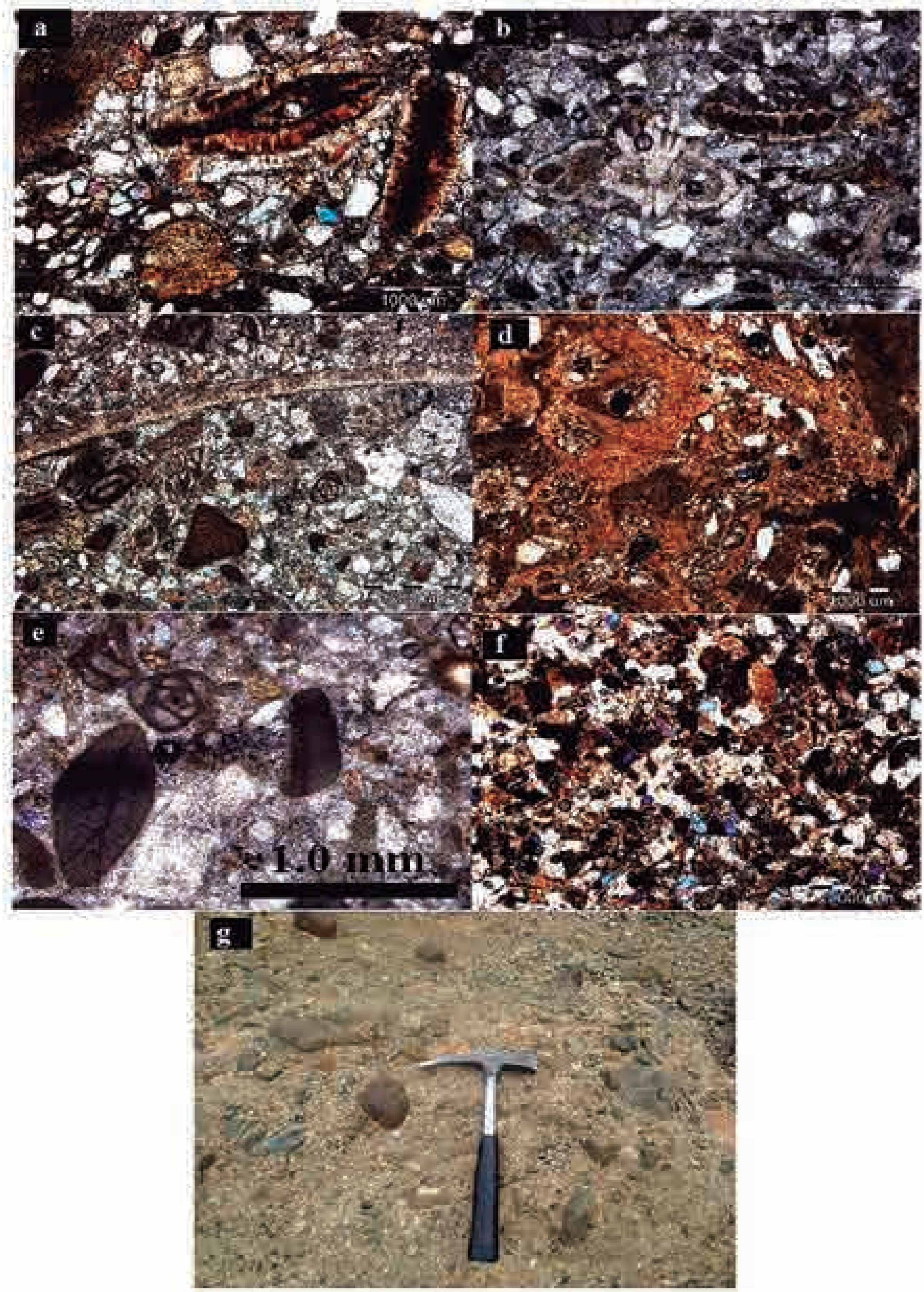

Figure 8 Facies of the Qom Formation at Ashtian area; (A) Biofacies B – Bioclastic *Operculina* Packstone; (B) Biofacies C – Bioclastic perforate foraminifera wackstone-packstone; (C) Biofacies D – Bioclast benthic foraminifera (perforate and imperforate) wackestone-packstone; (D) Facies E – Fine to medium sandstone: calcite cemented submature litharenite; (E) Biofacies F – Bioclastic imperforate foraminifera corallinacean wackstone to packstone; (F) Biofacies G – Bryozoans corallinacea bioclastic wackestone-packstone; (G) Facies H – Gms (gravel with massive layering and abundant matrix).

the oligophotic zone in a shallow open marine environment with low energy or near a fair-water wave base on the proximal middle shelf (Geel, 2000). A similar microfacies has also been reported of Qom Formation in Navabn section (Sadighi *et al.*, 2009).

5.3 Facies C: Bioclastic Porferate Foraminifera Wackstone-Packstone (Figure 8B)

This facies occurs in lower part of unit3. The main characteristic feature of this facies is the abundance of perforate hyaline benthic foraminifera (*Amphistegina* sp., *Elphidium* sp., *Neorotalia* sp.). Other components of this facies include echinoids, gastropoda and bivalves. The matrix is fine- grained micrite. Inorganic particles are medium sorted and rounded quartz. Megascopically, this facies is composed of very soft green marly limestone.

Interpretation: The presence of high diverse stenohaline fauna such as echinoid and larger foraminifera indicate that the sedimentary environment was situated in the oligophotic zone and normal salinity in a shallow open marine environment or near a fair-water wave base on the proximal middle sramp (Pomar, 2001; Vaziri Moghaddam *et al.*, 2010) and in the upper part of the upper photic zone (Bassi *et al.*, 2007).

Wilson & Vecsei (2005) show an association of red algae with large foraminifera such as *Neorotalia* deposits in an oligophotic zone under tropical to subtropical conditions and in a shallow open marine environment or near a fair-water wave base on the middle shelf. Murray (1991) suggested for the *Neorotalia* an open condition of open marine platform conditions with water depth in the order of 20-50 mbsl. Amin Rasouli (2005) reported a similar microfacies from middle ramp from the Qom Formation in south Central Iran.

5.4 Biofacies D: Benthic Foraminifera (Perforate and Imperforate) Bioclast Wackestone- Packstone (Figure 8C)

This biofacies occurs in unit 2. It is composed of very soft cream marly limestone and variable proportion of benthic foraminifera. Porcelaneous foraminifera (*Pyrgo simplex*), hyaline foraminifera (*Bolivina plicatella, Elphidium* sp.) are the most important foraminifera in this microfacies. The matrix is fine grained micrite.

Interpretation: Hallock & Glenn (1986) reported that an association of *Elphidium* and miliolid reflects water depth environment below 35 m that deposition took place in the inner shelf environment. Today, porcelaneous larger foraminifera thrive in tropical carbonate platforms within the upper part of the photic zone (Bassi *et al.*, 2007). Some biogenic components such as miliolids indicate stress conditions within restricted environments. The predominance of mud-rich lithologies with oligotypic fauna (such as miliolids) and the presence of a low-diversity foraminiferal association indicate deposition in a low-energy with poor connection with open marine and/or extreme salinities circulation and probably reduced oxygen contents or euryhaline conditions (Geel, 2000). Such an assemblage described to be associated with an inner ramp environment (Vaziri-Moghaddam *et al.*, 2004).

A similar facies with imperforate foraminifers and perforate foraminifers was reported from the inner ramp of the Oligocene-Miocene sediments of the Zagros basin at Kabir Kuh, Darre Shahr and Mamolan sections (Vaziri-Moghaddam *et al.*, 2006).

5.5 Facies E: Fine to Medium Sandstone - Calcite Cemented Submature Litharenite (Figure 8F)

This facies occurs in unit 5 and lower part of unit 1. Megascopically, this facies is composed of whith sandstone. Quartz is the main component in this facies. Frequency of plagioclase is negligible. Also, chert, siltstone, calcareous rock fragments exist. The glauconite minerals rarely present. The textural and maturity of the sandstones of these deposits is sub-mature or mature.

Interpretation: As Tucker (2001) showed, presence of lithic grains revealed that the sedimentary basin was a near-origin environment. The features of components and the stratigraphic position and the presence of marine trace fossil (*Kuphus* sp.) support that it has been probably barrier, and it is comparable to barrier of between back ramp and inner ramp

(Burchette & Wright, 1992). Flügel (2010) showed, in the coastal environment, the clastic sediments may originate from the bedload of estuaries. The coastal sandstone beds of the Qom Formation have been already identified (Amirahahkarki *et al.*, 2015).

5.6 Facies F: Bioclastic Foraminifera Corallinacean Wackstone to Packstone (Figure E)

This facies occurs in upper part of unit 1 and is characterized by a high diversity of benthic biota, including porcelaneous and agglutinate foraminifers (*Miliola* sp., *Triloculina* sp., *Quinqueloqulina* sp., *Schlumbergerina* sp., *Spiroloculina* sp., *Spiroclypeus* sp., *Peneroplis* sp.), corallinacea (*Subterraniphyllum* sp., *Lithophyllum* sp., *Mesophyllum* sp.), bryozoans (*Tubucellaria* sp., *Onychocella* sp., *Cellepora* sp.), echinoderms, bivalves, gastropoda and coral. Typically, it has a rudstone texture with wackestone-packstone matrix. Megascopically, it is medium-bedded to thick-bedded olive green limestone.

Interpretation: Brandano *et al.* (2010) showed corallinacean algae are present in water depth environments ranging from 0 to 286 m. Hallock (1999) proposed that the occurrence of abundant miliolids and agglutinate foraminifera (*Schlumbergerina* sp.) and corallinacean algae indicates the shallowest water depth of environment and may point to the depositional environment being slightly hypersaline. Lee (1990) reported that some porcelaneous imperforate foraminifera (*Peneroplis*) live in recent tropical and subtropical shallow water environments, hosting dinoflagellate, rhodophycean and chlorophycean endosymbionts. Therefore, Brandano *et al.* (2008) knew that the presence of epiphytic foraminifera in the microfacies is due to sea-grass-dominated environments. The predominance of mud-rich lithologies with oligotypic fauna (such as miliolids) indicates deposition in a low-energy with poor connection with open marine. Recent miliolids are euryhaline forms living in shallow restricted environments with low turbulence thriving on soft substrates. When they are present in great abundance, Geel (2000) described, miliolids may indicate nutrient-enriched conditions. Since nutrients are abundant and water is shallow, and due to the foraminiferal assemblage, F biofacies belongs to the shallow environment, and probably to the semi restricted lagoon.

Vaziri Moghaddam *et al.* (2010) and Amirshahkarami & Karavan (2015) reported a similar microfacies from inner ramp from the Asmari and Qom Formation, respectively.

5.7 Facies G: Bryozoans Corallinacea Bioclastic Wackestone-Packstone (Figure 8F)

This facies occurs in upper part of unit 1. The textures are wackestone-packstone. The matrix consists of micritic. Bryozoans and corallinacea red algae are dominant components in this microfacies. Other bioclasts are rare but include bivalvia. No foraminifera were found in this unit.

Interpretation: Hallock (1985) reported that larger benthic foraminifera have highly adapted to stable, oligotrophic and nutrient-deficient conditions, but they cannot respond competitively when nutrient resources become abundant. Unlike foraminifera, bryozoans have adapted to the eutrophic conditions. Probably, the presence of abundant bryozoan on facies G indicates that the condition was highly eutrophic. Moreover, Nebelsick *et al.* (2005) reported that the presence of well-preserved coralline algae indicates a relatively quiet-water environment with stable substrate and low sedimentation rates. Brandano & Corda (2002) showed the presence of bryozoans indicate an increase in heterotrophy. They proposed that red algae with bioerosion suggest a change from oligotrophic conditions to a high level of nutrients. Depositional textures, fauna and flora and the stratigraphic position show that sedimentation may have taken place in warm, euphotic and shallow water, with low energy conditions. G biofacies belongs to the semi-restricted lagoon. Amirshahkarami & Karavan (2015) reported a similar microfacies from Qom Formation.

5.8 Facies H: Gms (Gravel With Massive Layering and aAbundant Matrix (Figure 8G)

This facies occurs in lower part of unit 1 and represents layers whose main parts are made of gravels. Gravel particles roundness varies from semi-rounded to rounded. Most of the space among the gravels consists of fine-grained sands and muddy sediments. The sediments are fairly well sorted. The amount of mud in these sediments is very few.

Interpretation: According to Mial (2006) and Rust (1978), gravels of conglomerate are wholly rounded because of their remoteness to the origin, and they include very large to very small gravels which are often very poorly sorted. This reflects the high energy of the environment at the time of depositional conditions. According to Mial (1977), the layers in pile situation are due to their formation in high energy and turbulent activity conditions. So, this facies is formed by debris actions with high viscosity and high power of environment. Fluvial channel current and debris flow are recommended on the basis of facies and lateral and vertical expansions in Gms facies.

6 Palaeoenvironmental Model

As shown in Figure 9A, the recognized facies have allowed the differentiation of two major depositional environments. These include ramp (inner, middle and outer) and back ramp (alluvium channel, restricted and semi-restricted) environments. Marl with abundant planktonic foraminifera was deposited in an outer ramp setting. As Flügel (2010) maintained, the presence of mud-supported textures and the apparent absence of wave and current structures indicate a low energy environment below storm wave base.

The mid-ramp is the zone between the fair-weather wave and the storm wave. Wackestone-packstone with *Operculina* and *Amphistegina* were deposited under low energy conditions, below the fair weather wave base (FWB) and above the storm wave base (SWB) in the middle ramp setting. The variation in the shape of the test reflects the differences in water depth. Foraminifera are the dominant microfauna of the middle ramp, probably because, as Romero *et al.* (2002) suggested, they were the best-adapted fauna to the paleoenvironmental conditions such as low hydrodynamic energy, lower limit of the photic zone, oligothrophy and normal salinity. The distal mid-ramp is differentiated from the shallower depth by decreased flatness and size of the perforate foraminifera and reduces of the number of porcelaneous foraminifera.

Proximal inner ramp conditions above the fair-weather wave base are characterized by mixed open marine fauna (such as perforate foraminifera) and the presence of protected environment fauna (such as miliolids).

Back-ramp sediments originate in restricted lagoonal areas (mudstone, wackstone and packstone) (Flügel, 2010). In the study areas, the back-ramp deposits consist of a semirestrcted lagoon, restricted lagoon and alluvium channel. Semi protected lagoon environments are characterized by biofacies types that include mixed open marine bioclasts (such as 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. The most abundant biofacies are medium to coarse-grained larger foraminifera with imperforate wall-bioclast wackestone-packstone. The presence of imperforate foraminifera 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 (Romero *et al.*, 2002).

Lagoonal plants and animals occupy different zones depending on their ability to tolerate salt concentration (salinity), wave action, river flow, tidal changes, and sedimentation levels.

In study section, the occurrence of large number of bryozoans and red algae indicate a eutrophic condition. High nutrient levels may be related to a high nutrient flux from land.

Facies E (Benthic foraminifera (perforate and imperforate) bioclast wackestone- packstone), facies F (Bioclastic foraminifera corallinacean wackstone to packstone) and facies H (gravel with massive layering and abundant matrix) are comparable to barrier, restricted and semi restricted lagoon and alluvium channel respectively.

7 Conclusion

On the basis of the foraminifera recognized at the studied section, the age of the Qom Formation is Late Oligocene (Chatting). Biogenic components of the Qom Formation are dominated by foraminifera, coralline red algae in association with Bryozoa. Based on biogenic components and textures, 6 biofacies and 2 lithofacies have been recognized and grouped into two depositional environments that correspond

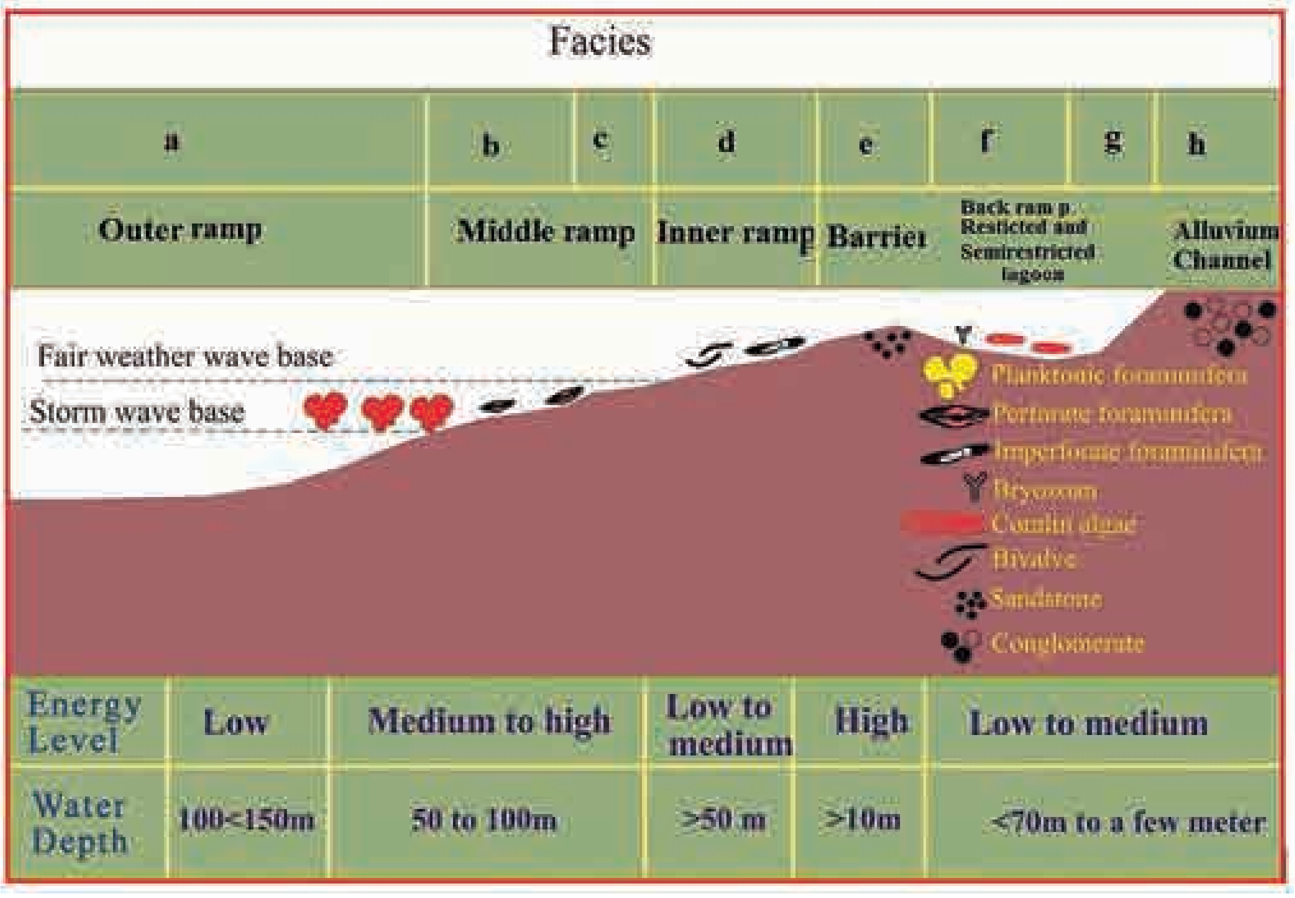

Figure 9 Depositional model for the Qom Formation in west of Ashtian.

to the ramp (inner, middle and outer ramp) and back-ramp (semi restricted lagoon, restricted lagoon and alluvium) environments. The biotic assemblages of the Qom Formation suggest that carbonate sedimentation took place in subtropical waters with oligotrophic conditions. Moreover, the abundance and association of Bryozoa with coralline red algae in the basal part of Qom Formation are referred to shallow warm water environments of the photic zone where eurytrophic condition was prevalent.

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