Identification of sedimentary environment and microfacies of Asmari Formation in one of the Lorestan basin oil fields

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Abstract

Depositional microfacies identification plays a key role in the exploration and development of oil and gas reservoirs. Asmari Formation in Oligo-Miocene is one of the most important reservoir Formations for the production and exploration of hydrocarbons in the Middle East and has a high reputation globally for a long time. In the Lorestan region, the sequences of the Asmari Formation have a carbonate-evaporate mixture of the late Miocene. The main aim of this research is to describe and interpret the different facies observations. Investigation of this sequence in one of the wells in this region has led to the identification of 17 sedimentary microfacies that belong to a homoclinal ramp-type carbonate platform. The nature and distribution of facies and environmental conditions of the Asmari Basin have undergone fundamental changes over time so that in the first part of this Formation (containing the first sequence of this Formation), the facies and their distribution pattern are similar to those of Tertiary and also others Zagros regions like Khuzestan and Fars. Still, in the second part (second sequence), there is a significant change in the Asmari basin, the most important of which is the replacement of red coral algae by a rare group of red algae with Aragonite wall. Our findings allows better characterizing and understanding which sedimentological features control the mechanical and its distribution throughout the formation.

Introduction

The Oligo-Miocene stratigraphic Zagros Basin, known as the Asmari Formation, is a prominent and important stratigraphic unit in the region and the world (Dill et al., 2020; Noorian et al., 2021). Due to their hydrocarbon properties, these rows have long been considered by national and international geologists (Zarei and Nasiri, 2021; Khalili et al., 2021; Li et al., 2021). From the stratigraphic point of view, in the Khuzestan region, Ahvaz sandstone and Kalhur evaporate members are two main constituents of the best reservoir unit of the Zagros region (Mahmoodabadi, 2020; Fallah-Bagtash et al., 2022).

Asmari Formation is a fundamental reservoir unit in the Zagros Basin and even the world has been studied many times. A large part of these studies arises from the it’s reservoir importance. The first published research article on Asmari belonged to Busk and Mayo (1918), who officially named their study collection Asmari and determined its age. Also, other studies related to sedimentary environment and sequence stratigraphy have been performed on Asmari formation (Sadeghi et al. (2010; 2009), Vaziri Moghadam et al. (2011) and Amirshah Karami et al. (2013; 2012), Mina Khatibi Mehr (2015), Adabi et al. (2016); Abyat et al., 2019; Lorestani et al., 2019; Jafari et al., 2021), Kak Mem et al. (2016)). Understanding the characteristics of sedimentology, stratigraphy, environment, and the formation of Kalhor evaporate member in this area are questions that have not yet received a comprehensive and documented answer. In this study, an attempt has been made to answer these gaps. Investigation of lithological and sedimentary properties, determining a comprehensive model for the sedimentation environment of these sequences, which in addition to carbonate sediments also deals with Kalhor evaporative sediments, investigation of their sequence stratigraphic characteristics, are the goals that have been tried to be done in this research.

Geological setting

In the study basin from the Early Oligocene to Early Miocene, deep marine facies and continental slopes are mainly deposited on the southwestern parts (Figure 1). Lagoon and tidal facies groups have mainly deposited in the upper part of Kalhor in sections related to a number of wells. Siliceous-clastic sediments of the sandstone section of Ahvaz have been seen in Dehloran and Cheshmeh fields, which are interlayer with carbonates of the Asmari Formation. Based on the combination of data from field studies, thin sections of wells, tidal zone environments, lagoon, continental slope and deep marine have been identified for the Asmari Formation. Investigation of field and microscopic data shows the deposition of Asmari Formation facies in a carbonate platform, which is suggested due to the lack of debris and turbidite flows in the Asmari Formation.

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The Zagros basin composes a thick sedimentary sequence that covers the Precambrian basement formed during the Pan–African orogeny (Al–Husseini, 2000; Pash et al., 2021). The total thickness of the sedimentary column deposited above the Neoproterozoic Hormuz salt before the Neogene Zagros folding can reach over 8 to 10 km (Alavi, 2004; Sherkati and Letouzey, 2004). The Zagros basin has evolved through a number of different tectonic settings since the end of the Precambrian (Gholamzadeh, 2021). The basin was part of the stable Gondwana supercontinent in the Paleozoic, a passive margin in the Mesozoic, and became a convergent orogen in the Cenozoic (Ghavidel-Syooki, 2021).

During the Palaeozoic, Iran, Turkey and the Arabian plate (which now has the Zagros belt situated along its northeastern border) together with Afghanistan and India, made up the long, vast and stable passive margin of Gondwana, which bordered the Paleo–Tethys Ocean to the north (Berberian and King, 1981; Ghorbani, 2021).

By the Late Triassic, the Neo–Tethys ocean had opened up between Arabia (which included the present Zagros region as its northeastern margin) and Iran, with two different sedimentary basins on both sides of the ocean (Berberian and King, 1981; Kordi, 2019; Bonnet et al., 2020).

The closure of the Neo–Tethys basin, mainly during the Late Cretaceous, was due to the convergence and northeast subduction of the Arabian plate beneath the Iranian subplate (Berberian and King, 1981; Stoneley, 1981; Beydoun *et al.*, 1992; Berberian, 1995; Sadooni & Alsharhan, 2019). The closure led to the emplacement of pieces of the Neo–Tethyan oceanic lithosphere (i.e., ophiolites) onto the northeastern margin of the Afro–Arabian plate (*e.g.*, Babaie *et al.*, 2001, 2005, 2006; Ghafur et al., 2020; Aldaajani et al., 2021).

Continent–continent collision starting in the Cenozoic has led to the formation of the Zagros fold and thrust belt, continued shortening of the mountain range, and the creation of the Zagros foreland basin. The Late Cretaceous to Miocene rocks represent deposits of the foreland basin before the Zagros orogeny and subsequent incorporation into the colliding rock sequences. This sequence unconformably overlies Jurassic to Upper Cretaceous rocks. Compressional folding began during or soon after the deposition of the Oligocene–Miocene Asmari Formation (Mapstone, 1978; Sepehr and Cosgrove, 2004).

During the Palaeocene and Eocene, the Pabdeh (pelagic marls and argillaceous limestones) and the Jahrum (shallow marine carbonates) formations were, respectively, deposited in the middle part and on both sides of the Zagros basin axis (Motiei, 1993). During the Oligocene–Miocene, this basin gradually narrowed and deposited the Asmari Formation. Different facies, including lithic sandstone (Ahwaz Member) and evaporites (Kalhur Member), were deposited during late Oligocene–early Miocene times (Ahmadhadi *et al.*, 2007; Monjezi et al., 2019). In the southwestern part of the Zagros basin, the Asmari Formation overlies the Pabdeh Formation, whereas, in the Fars and Lurestan regions, it covers the Jahrum and Shahbazan formations (figure 1). Although the lower part of the Asmari Formation interfingers with the Pabdeh Formation in the Dezful Embayment (Motiei, 1993), its upper part covers the entire Zagros basin.

Among the complex tectonic framework of the Middle East, the Zagros fold-thrust belt is the deformed state of the Zagros sedimentary basin. The Zagros fold-thrust belt, with an extension of about 2000 km from southeastern Turkey to northern Syria and Iraq to south and west of Iran, is the most oil-rich fold-thrust belt in the world with its numerous and very large hydrocarbon fields (Mosaadegh et al., 2009). Also, Zagros is divided into Khuzestan, Fars and Lorestan regions based on some structural and geographical features (figure 2).

The name of the Asmari Formation is taken from Asmari Mountain located southeast of Masjed Soleiman and the place of its geological section. First studied by Richardson (1924), it consists of 314 meters of rough limestones, it is cream-brown with a steep morphology that has shaly interlayers and its prominent feature is having a lot of joints, but in the lower part of the geological section is not seen, and Wynd (1965) believes that Pabdeh shales and marls have replaced this part. In the geological section of the Asmari Formation, its lower boundary is limited to Pabdeh Formation and its upper boundary is limited to Gachsaran (Motiei, 2003).

This Formation is the youngest and most important reservoir rock in the Zagros region, so oil was discovered for the first time in the Middle East and this reason led to extensive studies have been conducted on various properties of this Formation (Aghanabati, 1383).

The lithological column of the Asmari Formation in the studied section, along with the Cenozoic stratigraphy of the Zagros Basin, is shown in Figure 3. The thickness of the Asmari Formation in this well is 184 meters. In the section related to its thickness, only the scale of its thickness has been drawn, and the depth that we have reached at the top of the Asmari Formation in exploration has not been determined. The studied samples include parts of the evaporative sequence of Gachsaran Formation, Marl, and limestone of Pabdeh Formation.

Material And Methods

Laboratory studies include the study of 145 thin sections prepared from Asmari Formation samples. According to the Dickson method, the thin sections were stained (Dickson, 1965). The classification and naming of rocks were based on the Dunham method (Dunham, 1962) and the model completed by (Ebrey and Klovan, 1971). In naming the samples, it has been tried to include all the main allochems in order of frequency. Accordingly, all allochems with a frequency of more than 10% are considered the main allochems. The main allochems are attached to the rock in order of frequency. Allochems with a frequency of between four and ten percent are considered sub-allochems and those with less than 4 percent are deemed partial allochems. The percentage of allochems was obtained using a visual method and compared with Baccelle and Bosellini's (1965) comparison tables.

The study of microfacies led to the identification of 17 facies in these sequences. To identify environmental features and interpret the environmental conditions of these facies, standard and common facies models, and modern models, have been used (Wilson 1975; Buxton & Pedley 1989; Pedley 1998; Flügel 2000).

Results And Discussion

Facies of Asmari Formation in the studied sections:

1. Tidal zone facies:

Mf1: Evaporites (Figure 4)

Mf2: Cryptalgal/Bioturbated/Dolomitized/Fenestrate or Pure Limemudstone (Figure 4)

2. restricted Lagoon Facies

Mf3: Bioclastic, Miliolidae, Moluska Wackstone-Packstone (Figure 5)

Mf4: Bioturbated, Pelloidal, Mudstone -Wackestone (Figure 5)

Mf5: Bioclastic, Ostracod, Rotalia Wackstone-Packstone (Figure 5)

3. Carbonate shoal facies:

Mf6 : Bioclastic Benthic Foraminifera, Peyssoneliacean Algae Rudstone- Grainstone (Figure 6)

Mf7 : Bioclastic, ooid Grainstone-Packstone (Figure 6)

Mf8 : Echinoid Oyster, Benthic Foraminifera, Red Algae Packstone-Grainstone (Figure 6)

4. Open marine (below normal wave base):

Mf10: Bioclastic, Benthic Foraminifera, Coraline Red Algae Rudeston -Packstone (Figure 7)

Mf11: Bioclastic, Echinoid, Porcelaneous Benthic Foraminifera, Peyssoneliacean Algae Boundstone (Figure 7)

Mf12: Peyssoneliacean Algae Boundstone (Figure 7)

Mf13: Bioclastic, Echinoid, Wackestone (Figure 7)

Mf14: Bioclastic, Echinoid, Bryozoer, larger Benthic Foraminifera Wackstone (Figure 7)

5. Open marine (below storm wave base):

Mf15 : Hemipelagic, Bioclastic Packstone-Grainstone or Tempestite (Figure 8)

Mf16 : Bioclastic, Planktonic Foraminifera Wackstone-Packston (Figure 8)

Mf17 : Bioclastic,Planktonic Foraminifera, Arenaceous Wackstone (Figure 8)

Sedimentary environment of Asmari Formation in the studied section:

The absence of significant reef facies and the absence of shallow bioclasts in deep areas, which is common in edged shelves, indicate the deposition of carbonate sequences of the Asmari Formation in a carbonate ramp (Tucker and Wright 1990; Flugel 2004). On the other hand, the presence of thick and energetic facies of Ooid grainstones (Mf7), which is an indicator of the ramp environment, is evidence of the deposition of this Formation in a carbonate ramp environment. The absence of Slumps, Breccia and turbidites in the facies of the deep sections of these sequences, which represent distally steepened ramp (Flügel 2013), indicates that the type of ramp in this basin was a homoclinal ramp. The distribution of facies across the ramp and their changes over time show the necessity of the describing of the Asmari ramp model by dynamic models (Flügel 2013). Based on studies and especially stratigraphic analyses of sequences, major changes are seen in the distribution of Asmari Formation facies over time. The facies of Asmari Formation sequences have significant differences from each other.

The facies model of the first sequence of this Formation is highly similar toconventional Tertiary models (Buxton and Pedley 1989; Pedley 1998; Pomar 2001) and equivalents of the Asmari basin. Also, the distribution model of facies and their nature is very similar to other sections of this formation in Khuzestan and Fars basins (Seyrafian and Hamedani 1998, 2003; Seyrafian and Mojikhalifeh 2005; Seyrafian 2000, Vaziri-Moghaddam et al., 2006; Amirshahkarami et al., 2007a, b; Mosadegh et al., 2009). However, the sequence characteristics of the upper part of the Asmari Formation are fundamentally different from the mentioned models. This is the unique presence of a group of red algae with an

Aragonite wall called Peyssoneliacean algae in this part of the Asmari Formation. This algal facies has never been reported in world geological records to this extent.

In this section, the most important Asmari facies, which are the main and most extensive facies, is the facies that is formed of this allochem. Also, one of the distinguishing features of Asmari Formation sequences in the studied field is the presence of extensive evaporative facies in it. Based on sedimentological and stratigraphic studies of sequences, these facies have been deposited in periods of low sea level and in the sedimentary basin, which indicates the restriction of the Asmari basin in the region in terms of hydrography, and as a result of its isolation, it becomes a shallow evaporative basin during periods of sea level decline (Emery and Myers, 1996; Warren 2006). These basins have a limited connection with water and open seas, and in periods of low sea level, their connection with open water is cut off, and the whole basin becomes an evaporative basin due to increased evaporation. Therefore, the sedimentation environment of the Asmari Formation in the mentioned region is a privileged case in the world. To simplify the sedimentary model of the Asmari Formation, its facies changes are described in the form of a conceptual model that expresses the sequences of the Formation.

Based on what was stated in the description and interpretation of the facies of Asmari Formation, the facies model of the sequences of this Formation along with the part of Pabdeh Formation which samples have been studied is shown in Figure 8. In this model, carbonate ramps can be divided into three sub-sections: outer ramp, middle ramp and inner ramp, based on energy levels. A facies zone expressing restricted carbonate Ooid shoals divided the shallow part of the ramp into two parts and the open sea (facies Mf7). This carbonate shoal is mainly made of thin-cortex Ooids such as non-pore foraminifera. The carbonate Ooid shoal facies are formed in the inner ramp's energetic parts and around the area where normal sea waves hit the seabed.. This zone is located under the lagoon environment in the section facing the beach.. Various facies have been deposited in different parts, all of which have the common feature of their low energy (facies Mf3, Mf4, Mf5). This feature is well observed in these facies' textural and compositional characteristics. These features include mud-dominated texture, Micriticization, Bioturbation, Miliolidae, etc. The last zone of the inner ramp section is the tidal zone (Mf2 facies). The predominant mud-dominated facies of this zone are characterized by features such as lamination structures, algal and microbial textures, stromatolite, evaporative crystals, and fenestral fabric.

The lagoon in this model seems to have been connected to the high seas by canals or periodic storms. The presence of Ooids in some facies near shoal (Mf3 facies) and the presence of bioclasts such as Bryozoans and Echinoderms that require free water circulation for life confirm this hypothesis. One of the most important facies of this model is located in the middle ramp, which contains red algae (Mf10 facies). This facies has become more Rhodolite towards the open sea and in the end parts, it interferes with the facies of large foraminifera. On the other hand, as Pedly (1998) has stated, these facies can extend to the zone of Ooid. Therefore, this is the broadest middle ramp facies. In general, it can be stated that in the upper parts of this facies zone, the main allochems that form the facies together with red algae are Benthic Foraminifera with Porcelaneous wall, the maximum frequency and variety of which is in the Euphotic Zone. Down the ramp and in the Photic Zone of the Euphotic zone or Mesophotic zone to the vicinity of the Oligophotic zone, these allochems give way to other allochems such as Echinoderms and Bryozoans.

In the upper parts of these facies and near the carbonate Ooid shoals, and in the most energetic part of the ramp environment, there is a Ptach Reef, which is located in the heart of the algal zone (Mf9 facies). This zone is in this ramp, and also, as Baxtun and Pedly (1989) and Pedly (Pedly, 1998) stated, it separates the middle ramp from the inner ramp. In other words, Ptach Reefs in the area where normal sea waves hit the bed floor have their maximum expansion. Thus, the broad zone of red coral algae expands so that its main part is in the middle ramp, but probably a small part of it has also spread in the inner ramp. The large floor Foraminifera zone is the deepest middle ramp facies formed in the Photic Zone and is one of the prominent zones of the Cenozoic ramps, and this zone overlaps with the upper-end parts of the algal facies (Mf14 facies).

The outer ramp has been identified by the presence of planktonic organisms as well as storm facies in this part of the Formation (facies Mf15, Mf16). These pelagic facies to deeper they are argillaceous and sandy and are considered deep basin facies in the study (Mf17 facies). Based on studies conducted in the Lorestan region, the ramp that belonged to the Asmari Formation in the upper part of the sequence of Asmari Formation to Miocene age was shallower than its initial part Oligocene age and early Miocene. Due to the lack of detection of storm waves effect area and conventional sediments in it, such as pelagic and storm facies, and detection of only the regular sea waves area, the upper part of the Asmari Formation sequence consists of two parts inner ramp and outer ramp and facies no carbonate shoal was identified.

The inner ramp is located above the base of the normal sea wave effect, and the middle and outer ramp are located above this part, as shown in Figure 9. In the model proposed for the Asmari Formation in Figure 9, The carbonate shoal facies separates the ramp into two parts, the restricted and the open marine. The carbonate shoal zone in the lower part of the Asmari Formation is of the Ooid carbonate shoal type and in the upper part of the carbonate sequence of the Asmari Formation is the bioclastic shoal type which the main allochem is the Aragonite Peyssoneliacean algae (Mf6 facies).

An important and unique event in this period of Asmari Formation deposition history is replacing of the red coral algae zone with the Peyssoneliacean red algae in the middle ramp. The algae sometimes form shells in the lagoon, but it is a sub-allochem and has managed to form a coverstone. The scattering of different facies along the carbonate sequence of the Asmari Formation from the tidal zone environment to the open marine environment in the studied section, along with the changes in the sedimentary environment, is shown in Figure 10.

Conclusions

- Laboratory studies identified 17 sedimentary facies in the sequences of the Asmari Formation. The distribution of facies and zones has changed fundamentally over time; In the first part of the Asmari

Formation, the distribution of facies is similar to the famous and conventional Tertiary models, especially the Miocene. In this section, the facies zone of red coral algae and the zone of large Benthic Foraminifera are the most prominent facies of the Asmari ramp that were deposited in the middle ramp section. The middle ramp is separated from the inner ramp by the energetic facies of the Ooid shoals. Plagic and storm facies were deposited in the outer ramp section. In addition to the shoal facies, which is formed in its most energetic part, low-energy facies were also deposited in the inner ramp.

- In the second part of the Asmari Formation, the facies of the Peyssonelid Boundstone replaces the red coral algae zone. The deepest facies belt of this section is deposited near the Mesophotic zone. The energetic facies of the Rudstone Peyssonelid represents the bioclastic shoal in this section. The shallow depth of the basin in this section and the formation of the Boundstone Peyssonelid facies indicate the shallow depth and low energy of the Asmari basin over time, which has led to environmental changes conditions and facies changes over time. It seems that these changes are the result of tectonic activity, which eventually led to the closure of the Proforland Basin in the Zagros. In this section, the Shoal zone is bioclast type.
- Peyssonelid algae in Asmari Formation have two facies, Rudstone and Boundstone. The Rudstone facies is found in energetic conditions with low bed stability and in the bioclastic shoal zone. In contrast, the wide Boundstone facies is seen in the low-energy parts and below the surface of normal sea waves effect and in the middle ramp. Optimal conditions for the life of these algae were low energy conditions below the normal surface of the sea waves, normal marine salinities, soft and muddy beds and light intensity from the photic zone to the maximum Mesophotic.

Declarations

Data availability:

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

Declarations Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have

appeared to influence the work reported in this paper.

Author's contribution

Nazanin Vakili designed and analyzed the data, wrote the manuscript. Ali Paknejadiyan and Kouros Yazdjerdi provided technical assistance and wrote the manuscript. seyed saeed mousapoor mousavi revised manuscript.

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Figures

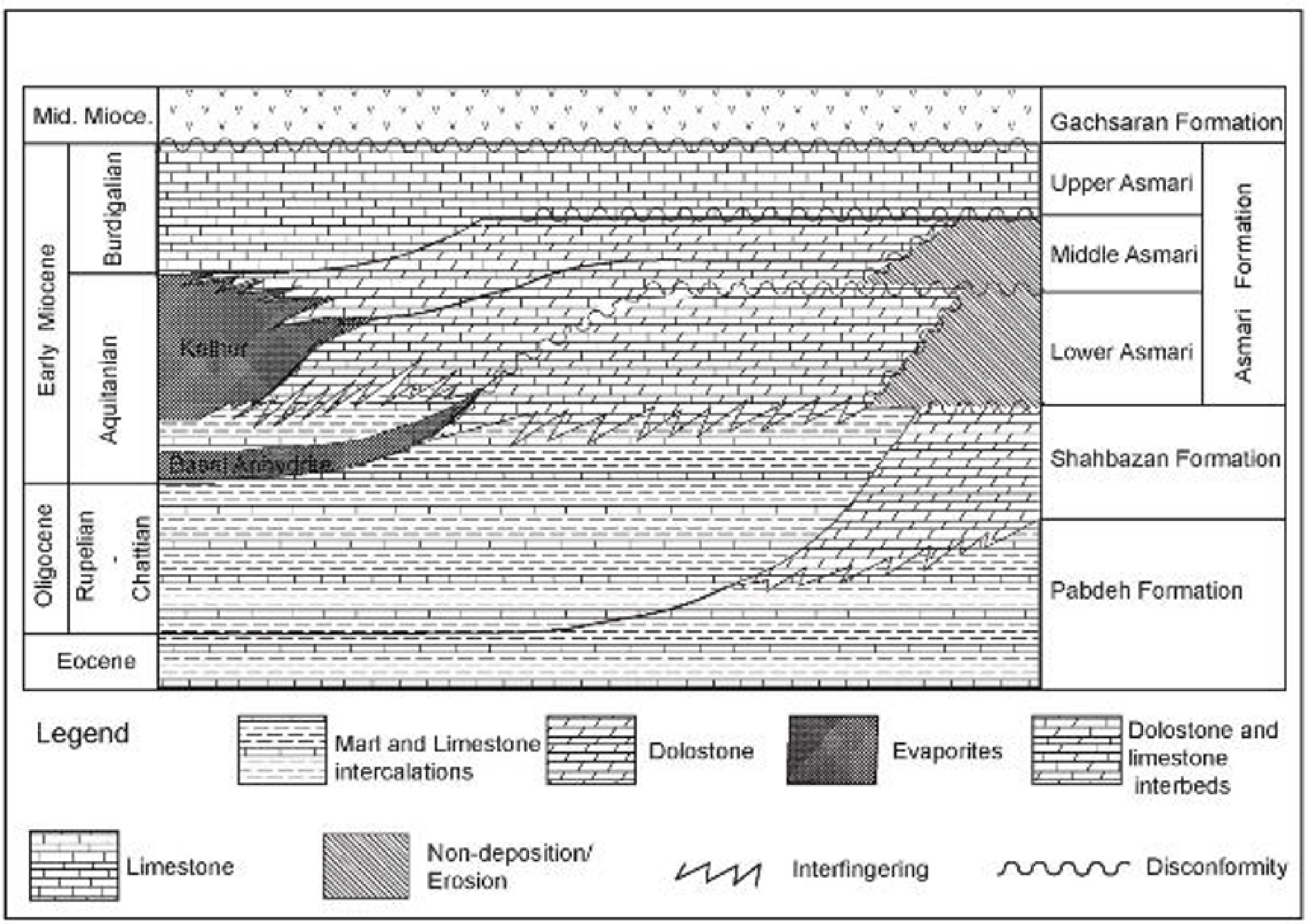

Figure 1

Stratigraphic column of the Asmari Formation in the study area (Motiei, 2001).

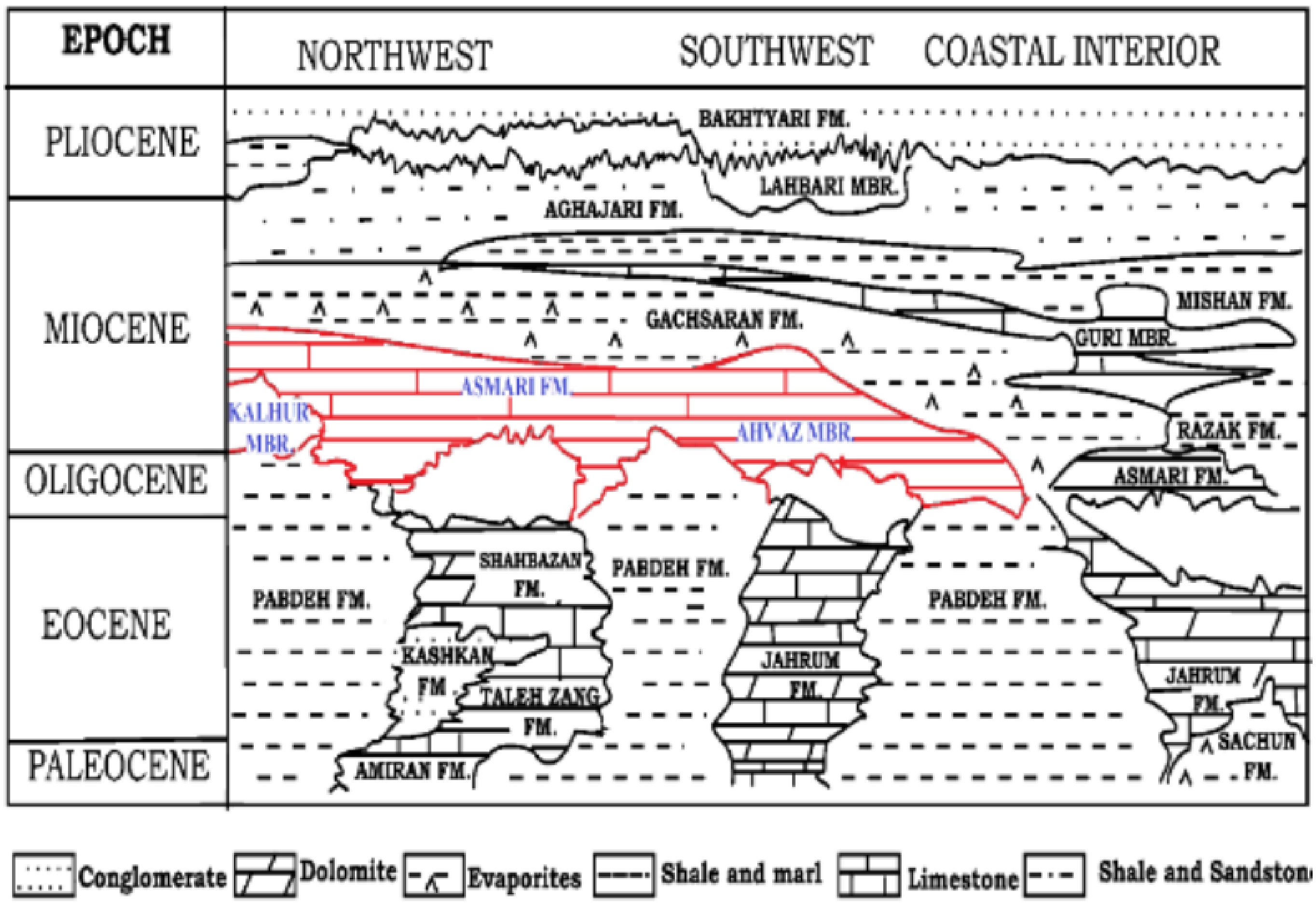

Figure 2

Schematic diagram of spatial and temporal distribution of the Zagros facies during the Upper Eocene to Lower Miocene. Adapted with slight modifications from (Ala, 1982)

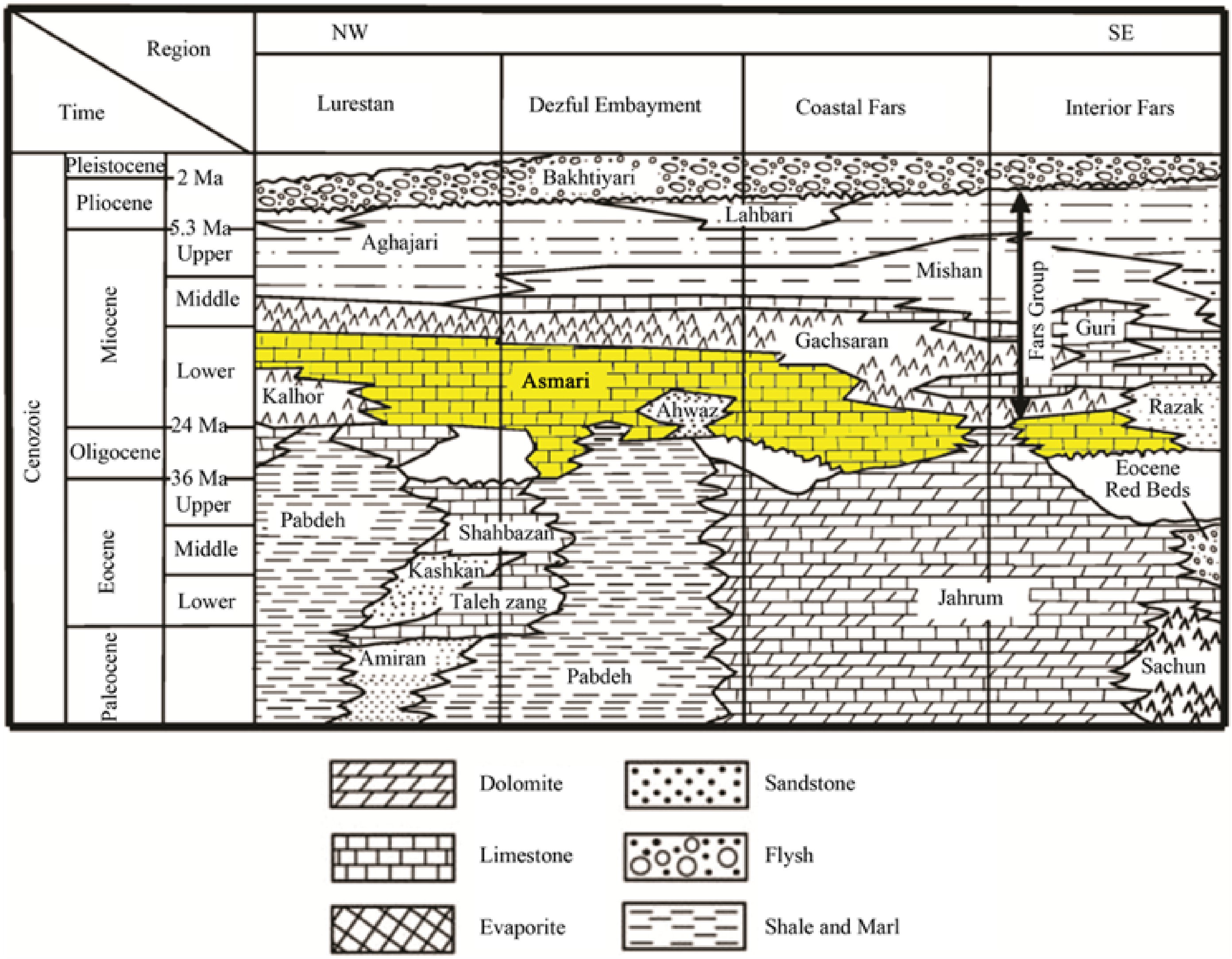

Figure 3

Cenozoic stratigraphy of the Zagros Basin, James and Wynd (1965)

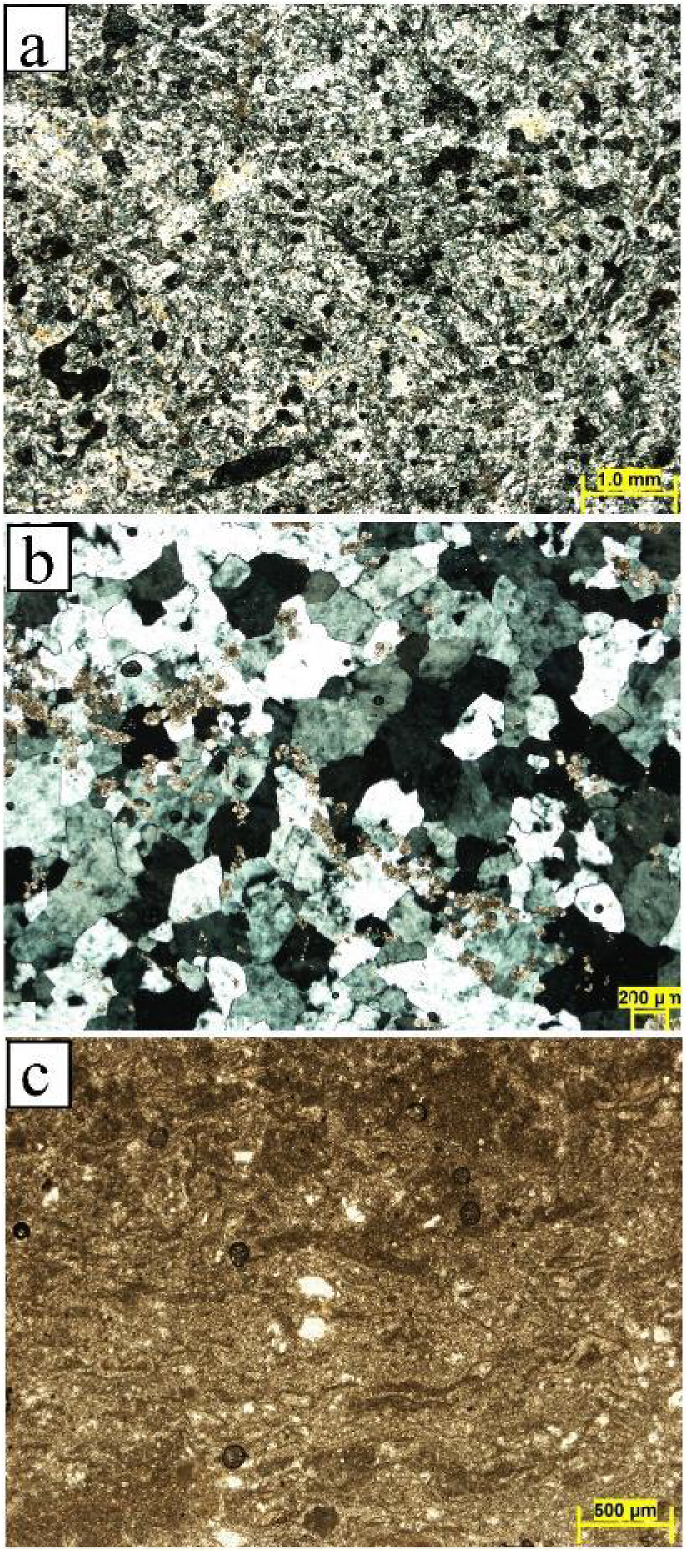

Figure 4

Tidal zone facies. a) Mf2 facies, alabasterine texture in Kalhor evaporites. XPL light; b) Mf2 facies, porphiloblastic texture in Kalhor evaporations note the fine carbonate lamination. XPL light; c) Mf1 facies are visible in the form of fine filaments of cyanobacteria. PPL light.

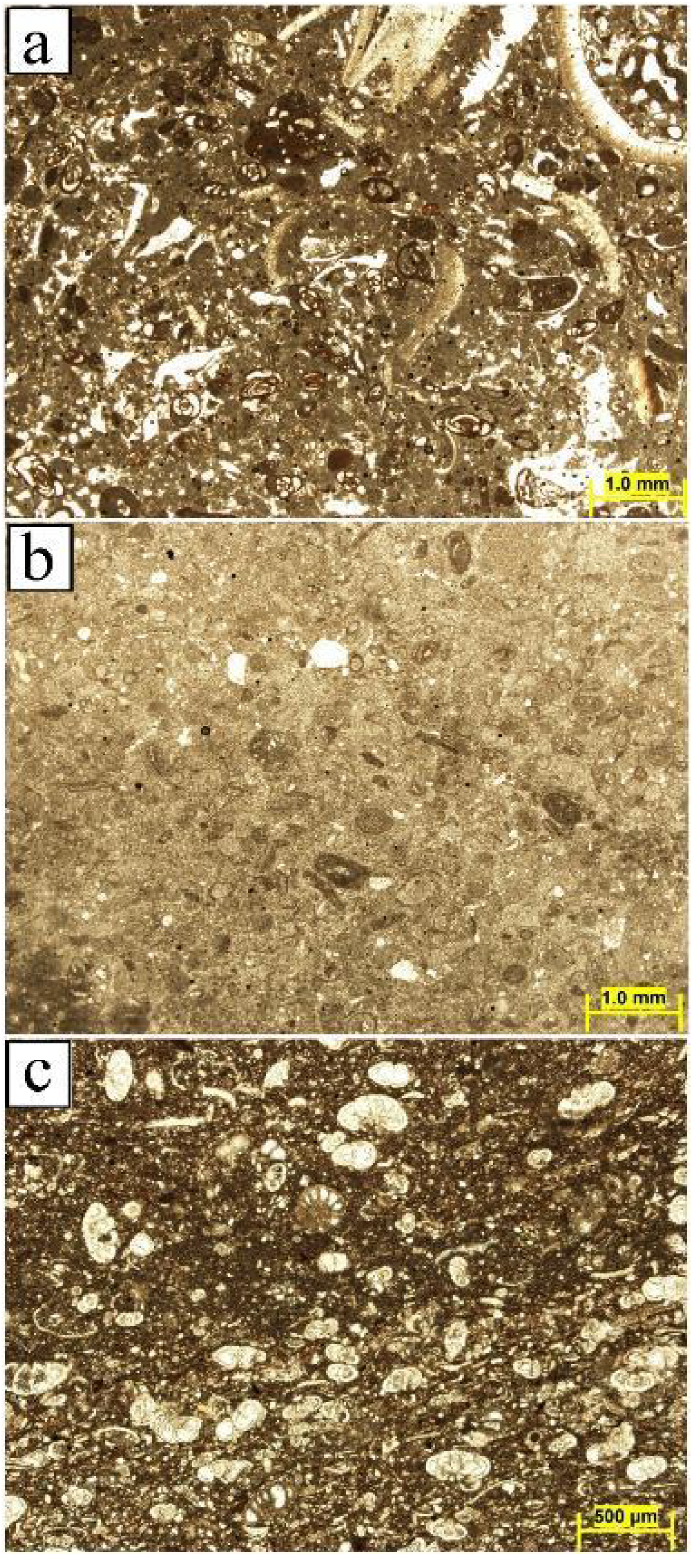

Figure 5

Facies related to the restricted lagoon environment a) Mf3 facies, in the form of foraminiferal Benthic Porcellaneou**s** foraminifera with scattered Moluska and Echinoderms in a microcrystalline text. PPL light; b) Mf4 facies, there are many effects of bioturbation in this facies. In addition to severe bioturbation, the image also shows a small amount of bioclastsic micrite that retains its ghost. PPL light; c) Mf5 facies, In the figure, bioclasts of Rotalia, Elphidium and Ostracoda are seen. PPL light.

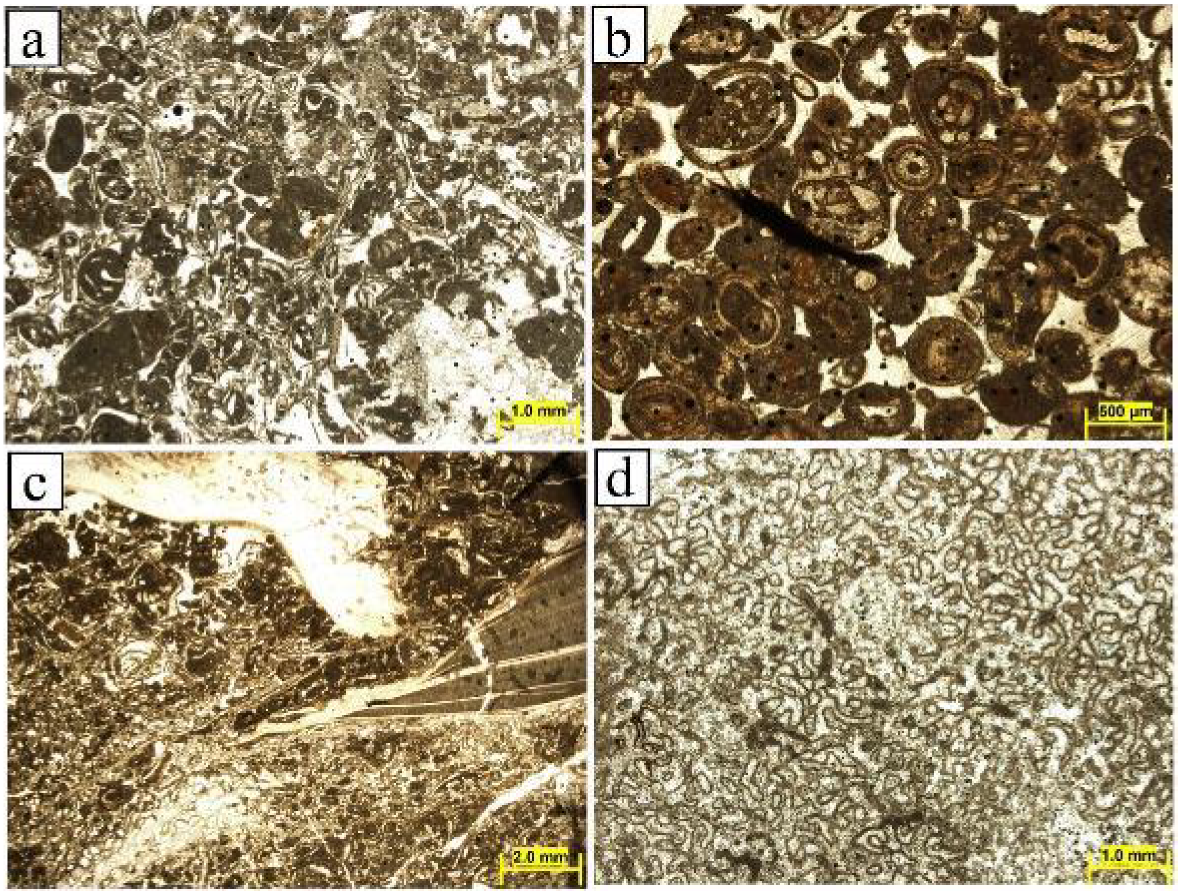

Figure 6

Mf6 facies: A variety of bioclasts are scattered throughout the Sparite cement. These include Porcellaneous foraminifera and green algae. PPL light; Note that thin and broken strands of algae are seen throughout the texture of the stone. PPL light; b) Mf7 facies: It is well seen in the form of scattering of Ooides in the cementitious text. PPL light; c) Mf8 facies: The oyster pieces are marked in the image. A piece of coral can also be seen in the lower-left corner of the image. Delicate shells of aragonite algae are scattered throughout the rock texture. PPL light; d) Mf9 facies: This facies is made of aragonite six-bladed corals. PPL light.

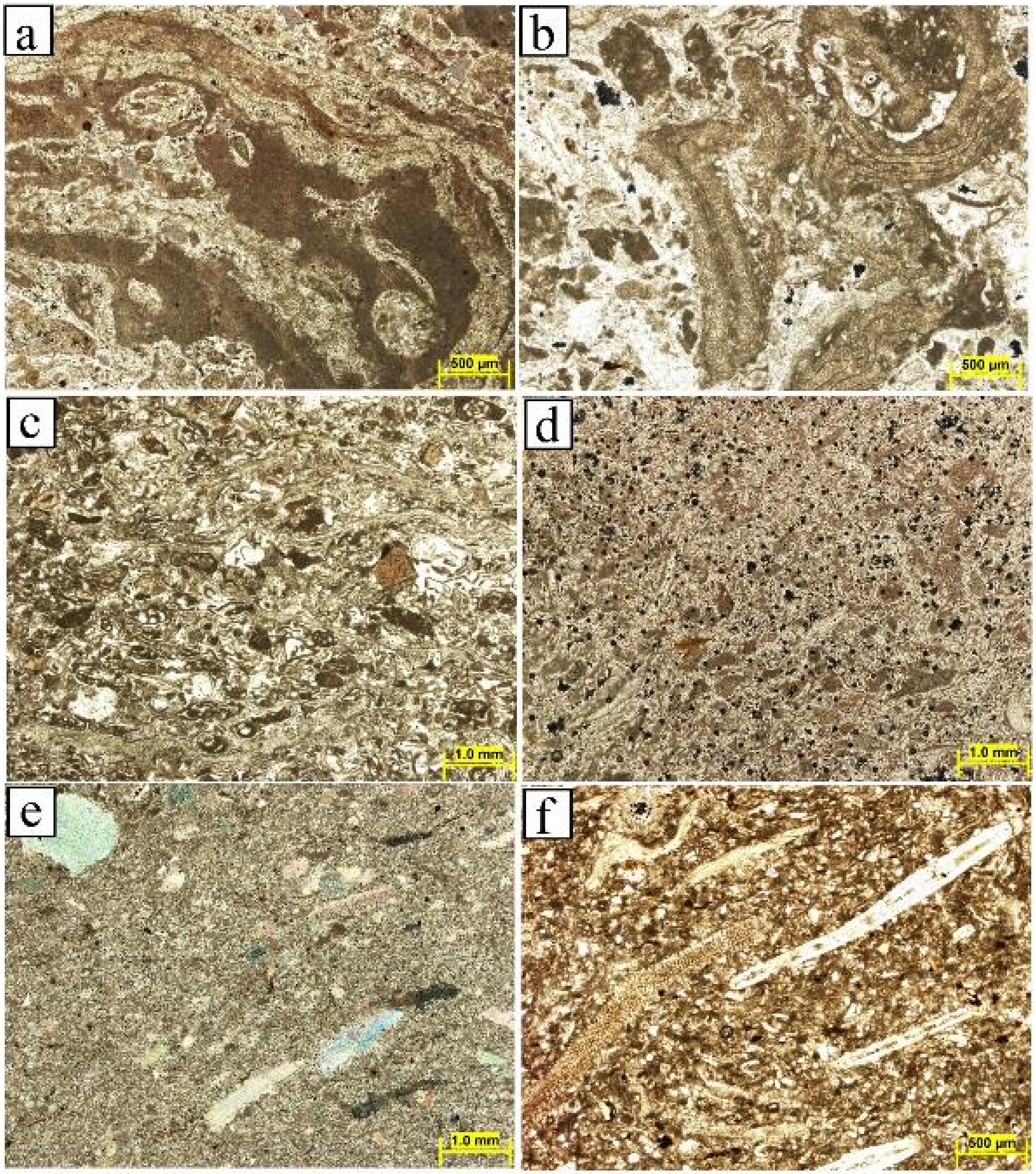

Figure 7

a) Co-growths of coral algae and Peyssoneliacean algae in Mf10 facies, facies are dark stripes of red coral algae and light bands of Peyssoneliacean algae. PPL light; b) Mf10 facies: Red coral algae are seen in these facies; PPL light, c) Mf11 Facies: Striped and arcuate shapes are all Peyssonelid algae from which the entire rock frame is composed. In the space between this frame, Porcellaneous-walled foraminifers are scattered. PPL light; d) This facies is made entirely of Peyssonelid algae. The aragonite skeleton of algae has dissolved in most parts. The space between the algal filaments is filled by micrite. XPL light; e) Mf13 facies: The skeletal parts of Echinoderms are scattered in the micritic texture. In this texture, very small bioclasts can be seen, which are also composed of crushed skeletons of Echinoderms.

XPL light; f) Mf14 facies: Large Benthic Foraminifera such as Operculina, Echinoderms and Planktonic organisms are the main features of these facies. PPL light

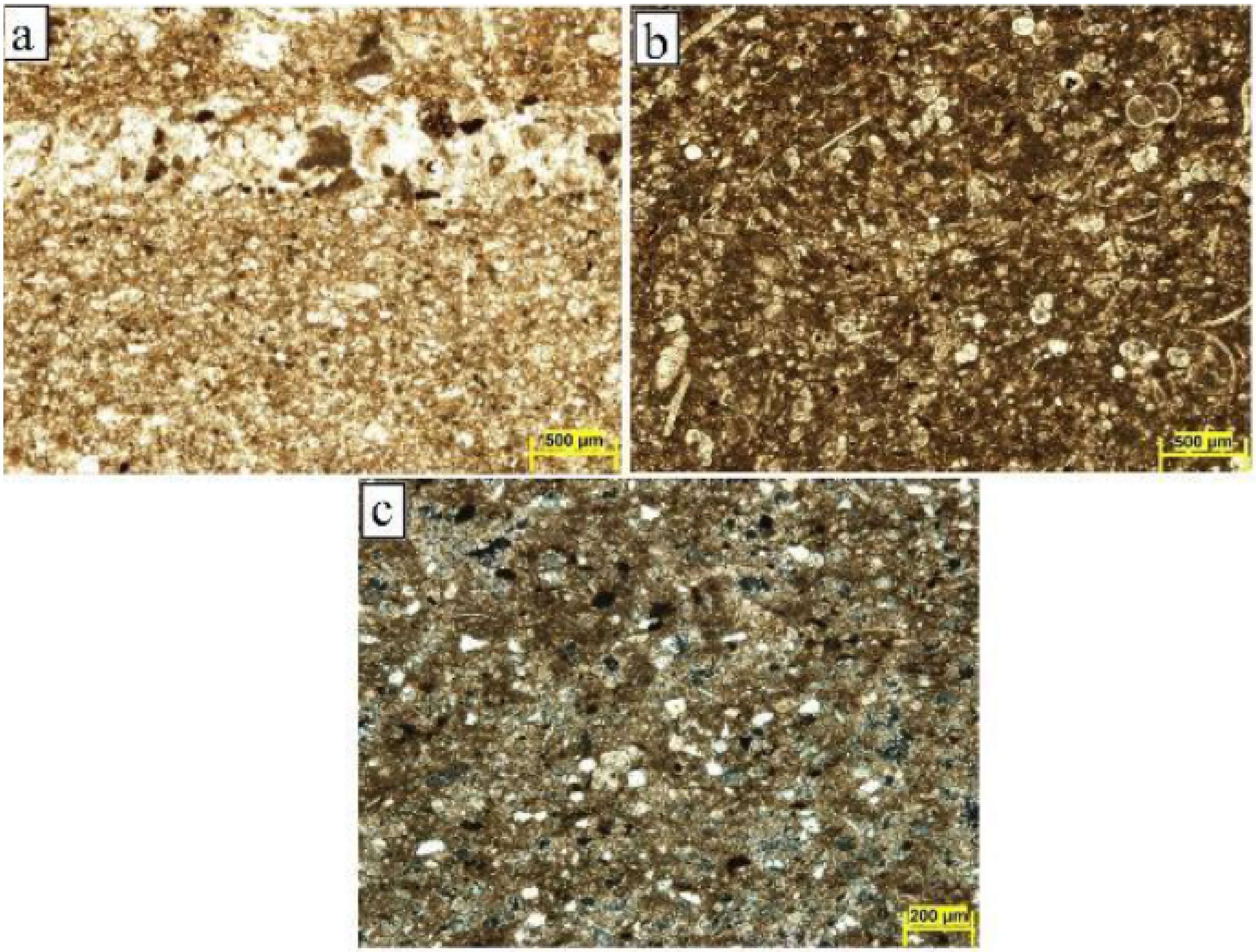

Figure 8

Facies Mf15: Note the mixing of shallow and deep allochems.a) Dark spots on light laminates are red coral algae. Laminates have a high percentage of allochems from shallow parts such as miliolida, PPL light; b) Mf16 facies: A high percentage of planktonic organisms in the image. PPL light; c) Mf17 facies: The scattering of quartz particles is evident in the micritic text. XPL light.

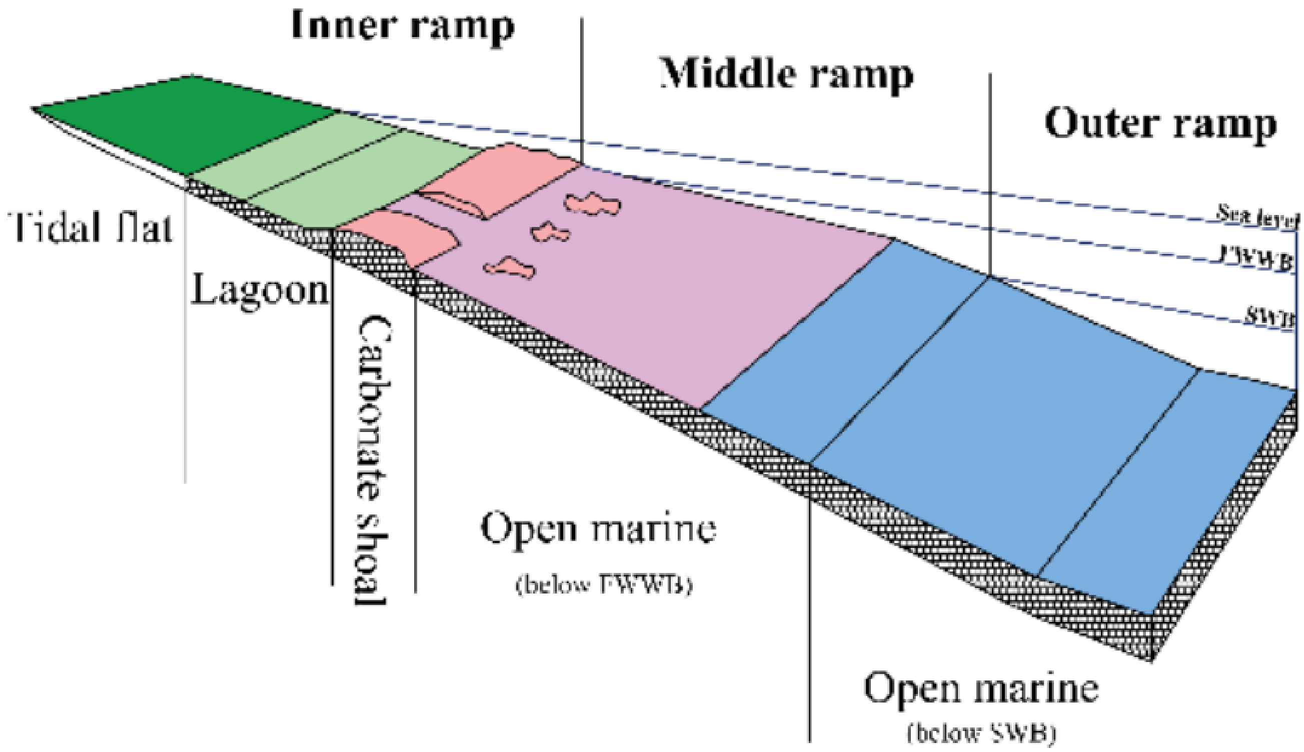

Figure 9

Sedimentary model for carbonates of the Asmari Formation in the studied section with subdivisions related to the sedimentary environment and energy levels related to sea waves that affect the seabed in different parts.

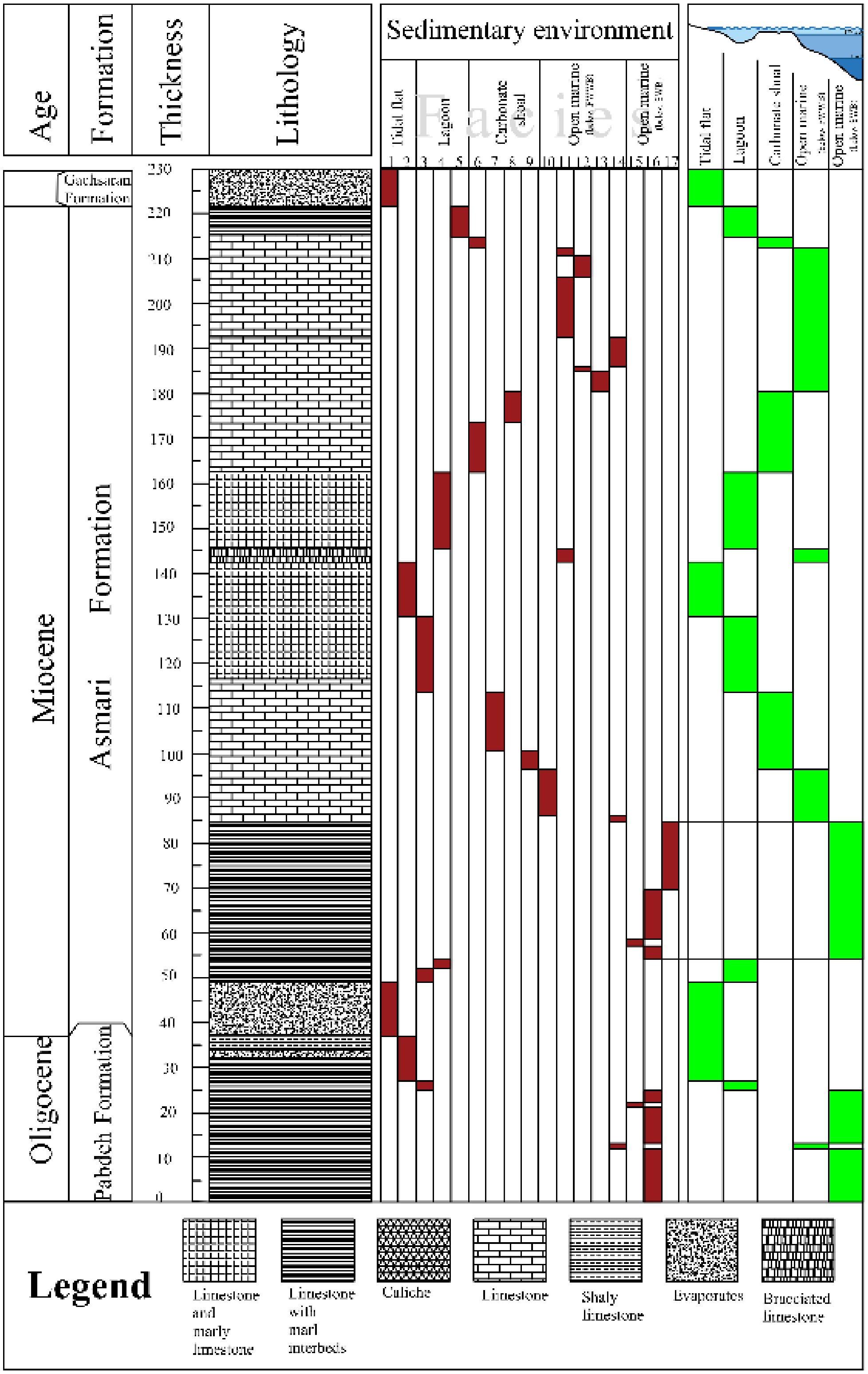

Figure 10

Distribution of Asmari facies and environmental conditions related to its sequence in the studied section over time.