Volume 16, Issue 2, 162411 (1-12)

Iranian Journal of Earth Science (IJES)

https://dx.doi.org/10.57647/j.ijes.2024.1602.11

Microfacies, sedimentary environment and sequence stratigraphy of Asmari Formation in North Western of Charam, Kohgilooyeh and Boyer Ahmad province, Iran

Behzad Saeedi Razavi[1,*], Saeedeh Senemari[2]

[1]*Construction and Minerals Research Group, Technology and Engineering Research Center, Standard Research Institute (SRI), Karaj, Iran.*
[2]*Department of Mining, Imam Khomeini International University, Qazvin, Iran.*

[*]**Corresponding author:** bsaidi@standard.ac.ir

Original Research Paper

Received:
21 January 2023
Revised:
5 March 2023
Accepted:
20 July 2023
Published online:
15 April 2024

Abstract:

The Asmari Formation is a thick carbonate sequence in the foreland Zagros Basin that was deposited during the Early Oligocene- Miocene. The Asmari Formation in North Western of Charam, Kohgilooyeh and Boyer Ahmad province was studied in terms of microfacies, sedimentary environment, and sequence stratigraphy. The upper boundary of the section is overlain by the Gachsaran Formation and lower boundary is overlain by the Pabdeh Formation. The studied section consists of limestone, marly limestone, shaly limestone, and intercalated of limestone, shaly and marl. Eighteen microfacies have been recognized. The study of allochemical, terrigenous, and orthochemical elements, infers that the different sedimentary sub-environments tidal flat, lagoon, barrier, and open marine for Asmari Formation. The Asmari Formation was deposited in on a ramp-type carbonate platform. Three complete sedimentary sequences and one incomplete sedimentary sequence were recognized.

Keywords: Microfacies; Sequence stratigraphy; Asmari Formation; Sedimentary environment; Carbonate platform

1. Introduction

The Zagros basin, it is a potential hydrocarbon reserves and young tectonic activity (Aghanabati, 2006). Among these, the Asmari Formation considered the world's oil reservoir it has long been the focus of many oil researchers in the world (Aghanabati, 2006). The maximum extent of the Asmari Formation is in the Dezful Embayment, but it also extends from the northwest to Iraq and from the south to Oman. The lithology is carbonate and Carbonates means limestone and dolomite, Cyclicity of shale and Limestone. The Asmari Formation has two evaporative members; Kalhor (southwest of Lorestan and northwest of Dezful Embayment) and Ahvaz sandstone (south of Dezful depression) (Motiei, 1993). The lower boundary of the Asmari Formation is represented by a paraconformity with the shales and marls of Pabdeh Formation In the center of Lorestan it shows an erosional discontinuity, is located on limestones and dolomites of Shahbazan Formation. In some areas of Fars, with erosional discontinuity, it covers Jahrom Formation. The upper boundary of the Asmari Formation, is with the evaporitic sediments of the Gachsaran Formation are in many parts of southwestern of Iran, which is covering the Asmari Formation with a same concordant, but in the interior of Fars, Razak Formation is replaced by the Gachsaran Formation as concordant on the Asmari Formation (Aghanabati, 2006) (Fig. 1). Among, researchers such as: Seyrafian (2000), Seyrafian and Hamedani (2003), Vaziri-Moghaddam et al. (2006); Vaziri-Moghaddam et al. (2010), Amirshahkarami et al. (2007a); Amirshahkarami et al. (2007b), Mossadegh et al. (2009), Allahkarampour et al. (2010), Sooltanian et al. (2011), Seyrafian et al. (2011), Allahkarampour et al. (2012), Yazdani (2014), Mirzaee-Mahmoodabadi (2014), Avarjani et al. (2015), Shabafrooz et al. (2015), Kangazian and Pasandideh (2016), Dehghanian (2017), Hatefi et al. (2018), Abyat et al. (2019), Monjezi et al. (2019), Karami et al. (2020), Rajabi et al. (2021),

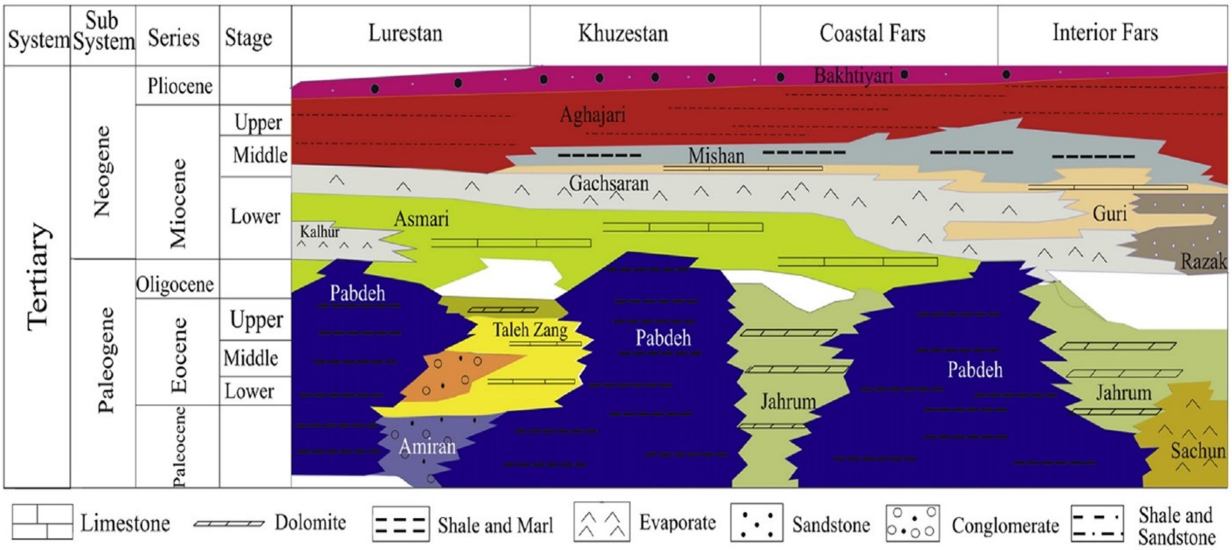

Figure 1. Expansion of Cenozoic stratigraphic rocks in the Zagros basin in Fars, Lorestan, and Khuzestan ((James and Wynd, 1965)).

Saeedi Razavi (2021) and Saeedi Razavi and Keshavarz (2022) have dispersedly evaluated this formation in terms of stratigraphy, sedimentary environment, microfacies and sequence stratigraphy. The objective of this study is to recognize the microfacies in order to describe the sedimentary environment, the conditions of facies formation and to resentation a sedimentary model and sequence stratigraphy model.

2. Geological setting

The Zagros Mountain is a fold and thrust belt that extends from southeastern Turkey through northern Syria and Iraq to western and southern Iran (Alavi, 2004). This orogenic belt is situated in the middle part of the Alpine Range. The belt is considered to be a passive eastern margin of the Arabian Shield (Stocklin, 1968; Berberian and King, 1981). The Zagros Basin was a part of the stable supercontinent of Gondwana in the Paleozoic, became a passive margin during the Mesozoic and then a convergent orogen in the Cenozoic (Bahroudi and Koyi, 2004). The Zagros Mountains consist of three zones: (1) the simply folded Zagros; (2) the imbricate thrust zone; (3) the Khuzestan Plain (Motiei, 1993). Based on the sedimentary history and structural style, Falcon (1961) divided the simply folded Zagros into several zones: Fars region, Lurestan region, the Dezful Embayment, the Izeh Zone, the Abadan Plain, the thrust zone, the Bandar Abbas Hinterland and the complex structure with metamorphic rocks (Heydari et al., 2003); Fig. 2 a. The studied section of Asmari Formation is 285 m in thickness and is located in the north western of Charam, Kohgilooyeh and Boyer Ahmad province with geographical coordinates of 30° 52′06″ N, 50° 41′45″ E. (Heydari et al., 2003); Fig. 2 b. It is located in the folded thrust zone of the Zagros Basin (Izeh Zone). 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 Formations (Fig. 3).

3. Materials and methods

Samples were collected at intervals of 1 to 2 m during fieldwork that included a thorough investigation of fossil and facies change studies. 145 thin sections, totaling 285 m in thickness, were produced in the section under study and carefully examined using a microscope fitted with a camera. The Gachsaran Formation lies on top of the investigated section's higher boundary, and the Pabdeh Formation lies on top of the section's lower boundary. Microfacies were established according on Flügel (2010), whereas limestone was designated based on Dunham (1962) and Embry and Klovan (1971). The methods and ideas of sequence stratigraphy are the principles for the sequence stratigraphy of the Asmari Formation (Haq et al., 1987; Van-Wagoner et al., 1988; Emery and Myers, 1996; Simmons et al., 2007).

4. Microfacies

18 microfacies were identified based on the assemblage of benthic foraminifera, planktonic foraminifera, and bioclasts (Fig. 3, Fig. 4, Fig. 5, Fig. 6, Fig. 8):

4.1 Fenestrate Mudstone (MF1)

This facies consists of fine-grained microcrystalline limestone, light brown, medium-bedded shaly limestone. Bioclasts are lacking and the fenestrate structures are well developed (Fig. 3 a, Fig. 3 b). Fenestrate structures are typical products of shrinkage and expansion, gas bubbles, and air escape during flooding, or may even result from burrowing activity of worms or insects. Shinn et al. considered similar facies representative of a tidal flat environment, where trapped air between irregularly shaped deposits leads to the development of birdseyes. A similar facies with this facies was reported from the inner ramp of the Oligocene-Miocene sediments of the Zagros basin (Vaziri-Moghaddam et al.,

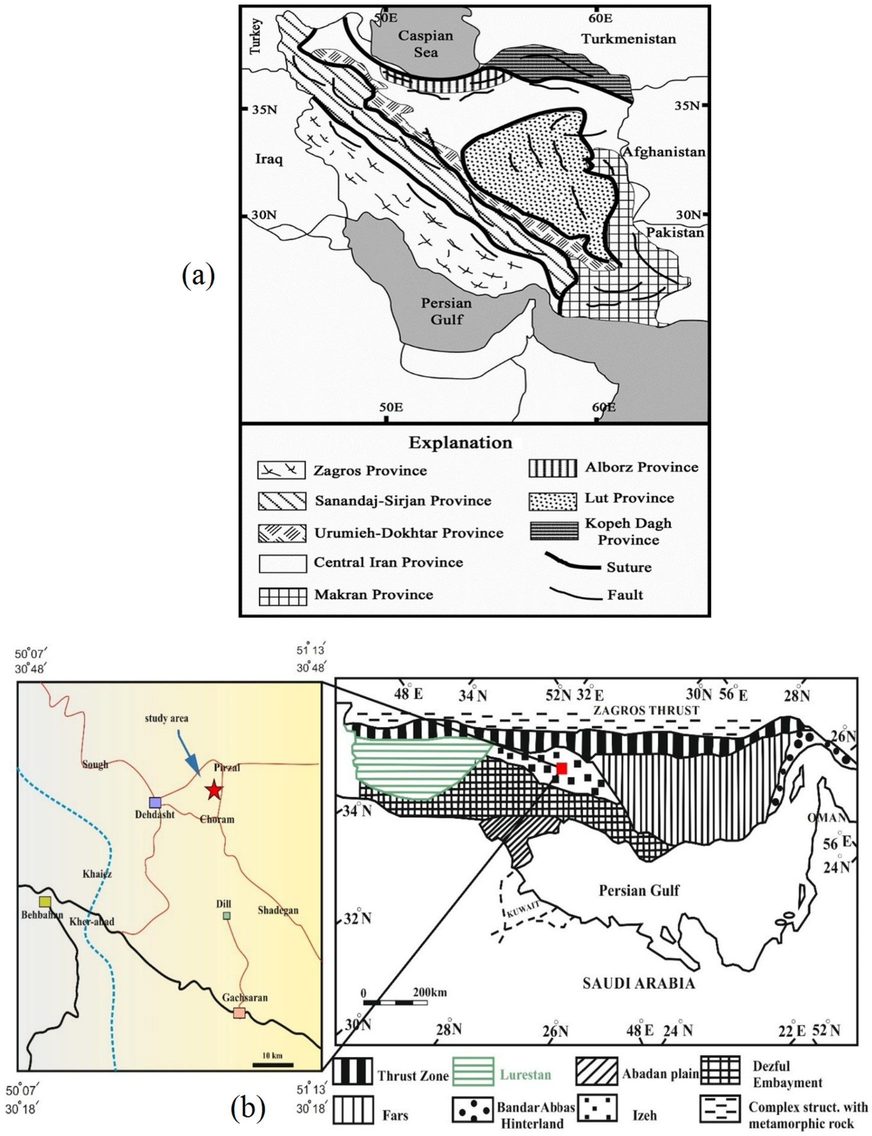

Figure 2. (a) Map of Iran showing eight geologic provinces. The study area is located in Zagros Province (adopted from (Heydari et al., 2003)). (b) Subdivisions of the simply folded Zagros belt (after (Falcon, 1961)).

2006; Sahraeyan et al., 2014; Kangazian and Pasandideh, 2016).

4.2 Fossil and quartz-bearing Mudstone (MF2)

Skeletal fragments (such as molluscs, gastropods, and bryozoans), Miliolid, as well as non-skeletal grains; quartz that are in the micrite background. The average percentage of matrix in this facies is more than 90%. (Fig. 3 c, Fig. 3 d). There is no evidence of subaerial exposure (such as a vesicular fabric, microcodium, birdseye and fenestral fabric) in lime mudstone in this microfacies. However, those unfossiliferous homogeneous micritic limes are interbedded with the lagoonal facies. Therefore lime mudstone with a paucity of fauna in this microfacies was deposited in a restricted lagoon (Tucker, 1990; Flügel, 2004). A similar facies was reported from the inner ramp of the Oligocene-Miocene Asmari Formation, in the central part of the Rag-e-Safid anticlinal oil field, Zagros Basin (Amirshahkarami, 2013). This Microfacies occurs at Dehluran, Kabirkuh (Darrehshahr section) and Mamulan of the Oligocene-Miocene Asmari Formation in the Zagros foreland basin (Vaziri-Moghaddam et al., 2010).

4.3 Miliolid / *Dendritina* / *Borelis* intraclast bioclasts Wackstone/Packstone/Grainstone (MF3)

Identifiable components of this facies include benthic imperforate foraminifera (*Borelis, Dendritina* and miliolids), skeletal fragments of molluscs, gastropods, and bryozoans. The grains are poorly to medium sorted, are fine-to medium size and vary from sub-angular to semi-rounded. Textures are dominantly packstone, but range from wackestone to grainstone. In some samples, the predominant non-skeletal carbonate grains are intraclasts (Fig. 3e, f, g, h, i, j). This facies was deposited in a restricted lagoon. The restricted condition is suggested by the rare to absent normal marine biota and abundant skeletal components of restricted biota (imperforate foraminifera such as *Borelis*, miliolids and

Dendritina). The subtidal origin is supported by the lack of subaerial exposure and stratigraphic position. This microfacies represents the shallowest upper part of the photic zone, with very light, highly translucent and soft muddy substrate (Geel, 2000; Romero et al., 2002; Corda and Brandano, 2003; Vaziri-Moghaddam et al., 2006; Bassi et al., 2007).

4.4 Miliolid ostracod Wackestone/Packstone (MF4)

The main components of these facies are imperforate benthic foraminifera (miliolids) and ostracods (complete shells and their shell fragments). The texture of the rock changes from the supporting mud or the supporting grain. In some sections, the percentage of ostracod decreases, and instead the fragments of shells of molluscs and echinoids are observed along with the miliolids, so that the name of the rock changes to the miliolids bioclast packstone (Fig. 4 a, b, c, d, e, f). Texture properties, an abundance of miliolids and ostracods, and the absence of stenohaline fauna indicate the deposition of the above sediments in a confined lagoon (Flügel, 2010).

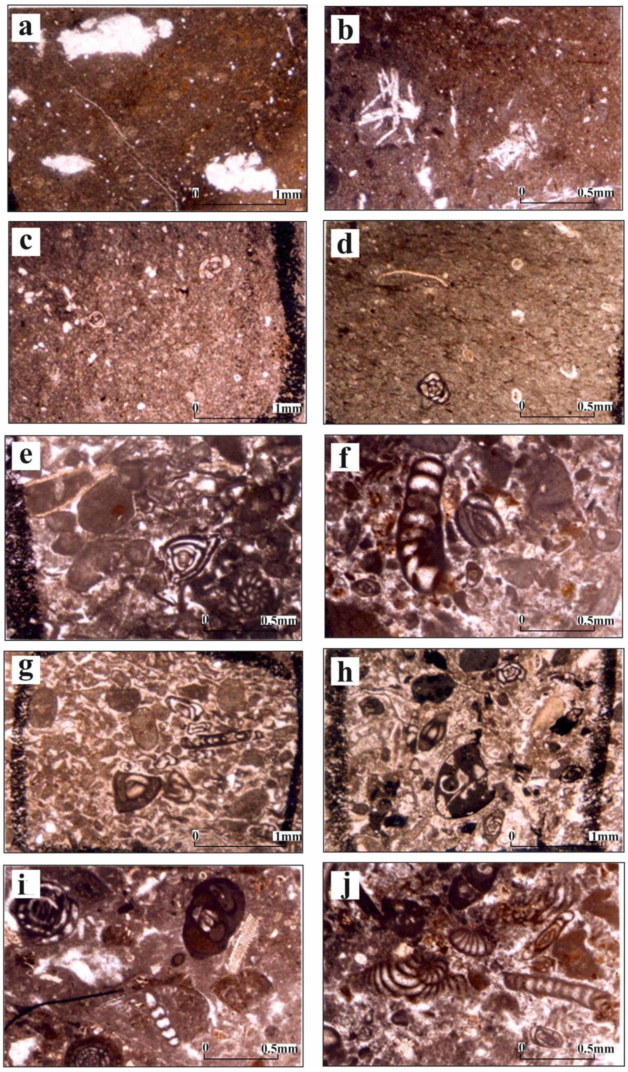

Figure 3. Microfacies of the Asmari Formation in the studied section. Mudstone with bird eye fabric (a), 25× magnification, mudstone with evaporative crystals mold (b), 40× magnification, fossilized and quartz-bearing mudstone (c), 25× magnification, fossilized Mudstone (d), 40× magnification, *Dendritina* miliolid intraclast packstone (e), 40× magnification, *Dendritina* miliolid intraclast packstone/grainstone (f), 40× magnification, *Dendritina* miliolid intraclast packstone/grainstone (g), 25× magnification, miliolid bioclast, intraclast, packstone/grainstone (h), 25× magnification , intraclast *Borelis* bioclast, packstone (i), 40× magnification, foraminifera interaclast packstone/grainstone (j), 40× magnification.

4.5 Miliolid peloids Wackestone/Packstone (MF5)

Identifiable components of this facies include benthic imperforate foraminifera (miliolids), peloids and to a lesser extent peneroplids. The grains are poorly to medium sorted, are fine-to medium size and vary from sub-angular to semi-rounded. Textures are dominantly wackestone to packstone (Fig. 4 g). Milioids are found in very shallow marine environments and are present in subhyaline to hypersaline environments in terms of the degree of salinity (Flügel, 2004). They are preferably found in low turbulence waters. The abundance of milioids indicates limited lagoons or relatively nutrient-rich environments behind the reef (Reiss and Hottinger, 1984). These microscopic facies is deposited in a lagoon and protected environment. The abundance of carbonate mud, peloids, and the abundance of benthic imperforate foraminifera confirm this.

4.6 Milioid Dasycladaceae Wackestone/Packstone (MF6)

In these microfacies, the skeletal grains of algae and milioid and small amounts of bryozoans, gastropods, and bivalves are located in the micrite background (Fig. 4 h, i). The presence of green algae (Dasycladaceae) and milioids indicates the formation of these facies in the calm oxygenated parts of the lagoon (Vaziri-Moghaddam et al., 2006; Brandano et al., 2009; Allahkarampour et al., 2010).

4.7 Bioclast Wackestone/Packstone (MF7)

In these microscopic facies, whole shells (longitudinal and transverse section) of gastropods, whole Ostracods shells, and skeletal fragments of green algae are the most abundant grains. In small quantities benthic foraminifera is also seen. Allochems are located in a micrite matrix (Fig. 7 j). In some sections, coral fragments and red algae (Corallinaceae) and bryozoans are also observed. The abundance of gastropods skeletal fragments and benthic imperforate foraminifera and also the absence of open marine organisms, the formation environment of this facies is attributed to the limited vegetated lagoon (Reiss and Hottinger, 1984; Geel, 2000).

4.8 *Dendritina* miliolid bioclast Packstone/Grainstone (MF8)

The skeletal components in these facies include imperforate foraminifera such as miliolids, especially *Dendritina*, bivalve, and gastropod skeletal components. The matrix often contains sprite cement that fills the space between the grains (Fig. 5 e). The texture of the rock, the abundance of miliolids, *Dendritina*, and the absence of offshore fauna indicate the formation of these facies in the energetic part

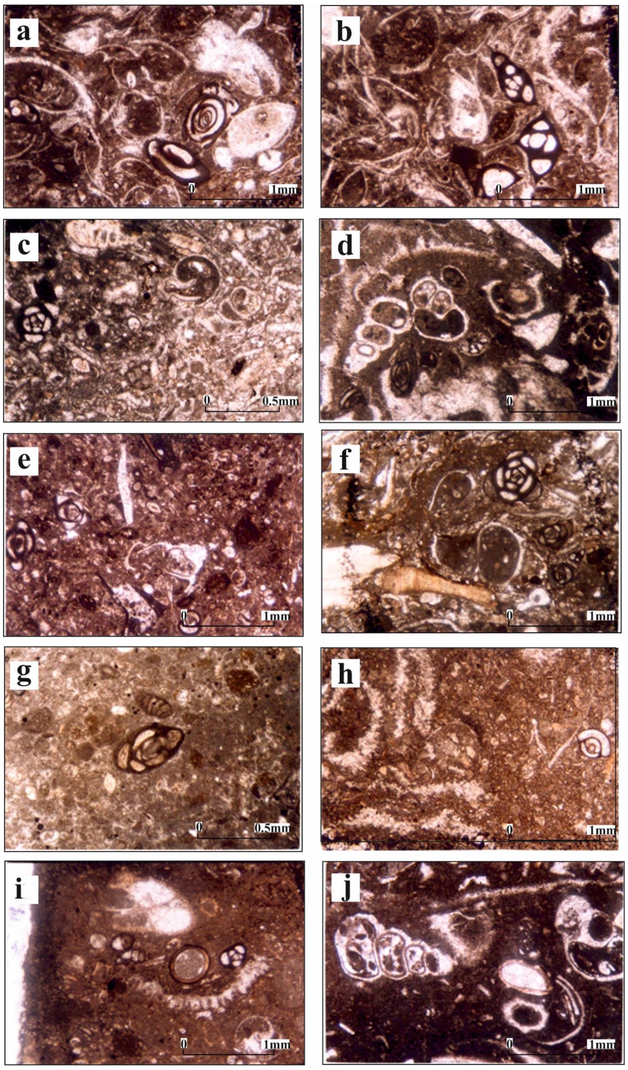

Figure 4. Microfacies of the Asmari Formation in the studied section. Miliolida Ostracoda packstone (a), 25× magnification, miliolida Ostracoda packstone (b), 25× magnification, miliolid bioclast packstone (c), 40× magnification, miliolid bioclast packstone (d), 25× magnification, miliolid bioclast wackestone/packstone (e), 25× magnification, miliolid bioclast packstone (f), 25× magnification, miliolid peloid wackestone/packstone (g), 40× magnification, miliolid Dasycladaceae wackestone/packstone (h), 25× magnification, miliolid bioclast Dasycladaceae wackestone (i), 25× magnification, bioclast wackestone/packstone (j), 25× magnification,

of the lagoon (Geel, 2000; Brandano et al., 2009).

4.9 Imperforate foraminifera Wackestone/Packstone (MF9)

In these microscopic facies, benthic foraminiferal shells without pores as miliolids (*Borelis* and *Dendritina*) are the most abundant grains. The background is a limestone facies that fills the space between the grains (Fig. 5 b, c). The abundance of benthic imperforate foraminifera in microscopic facies indicates their formation in a lagoon environment (Hottinger, 1997; Geel, 2000).

4.10 Miliolid *Borelis* bioclast Wackestone/Packstone (MF10)

The predominant skeletal grains of these facies are imperforate foraminifera as miliolids (*Borelis*), other foraminifera as *Textularia* and *Rotalia*, and fragments of mollusca, coral, and ostracod. The empty space between the grains is filled with limestone and the texture of the grain is supporting. In some sections, *Dendritina* replaces *Borelis* (Fig. 5 d). The textural characteristics and abundance of benthic imperforate foraminifera indicate the deposition of these facies in the lagoon environment (Hottinger, 1997; Geel, 2000; Wilson, 1975) reported similar facies from lagoon environments.

4.11 Milioid, *Borelis*, *Meandropsina* bioclast Wackestone/Packstone (MF11)

The fossil grains of these microscopic facies mostly include benthic imperforate foraminifera (Milioid, *Borelis*, *Meandropsina*), echinoid and bivalve fragments. A micrite background surrounds the above grains (Fig. 5 e). The abundance of benthic imperforate foraminifera and mud-supporting rock texture indicates the formation of these facies under the lagoon environment (less energetic part) (Vaziri-Moghaddam et al., 2006; Brandano et al., 2009; Allahkarampour et al., 2010).

4.12 Rotaliida Bioclast Echinoid Wackestone/Packstone (MF12)

In these facies microscopic, benthic perforate foraminifera (Rotaliida) and complete shells and fragments of ostracod and echinoid shells are the most abundant grains. In addition to the above components, very small amounts of benthic small foraminifera and destructive quartz are also seen. The texture of the rock varies from the support mud to the support grain and the grains are in a micrite background. In some sections, as the percentage of ostracod increases, the name of the rock changes to *Rotalia* ostracod wackestone/-packstone (Fig. 5 f, g, h). The location of the above facies in the sedimentary sequence with lagoon facies indicates the formation of these facies in the semi-limited lagoon section (Flügel, 2004; Geel, 2000; Corda and Brandano, 2003).

4.13 Rotaliid *Dendritina* miliolid Wackestone/Packstone (MF13)

The main components of these microscopic facies are perforate foraminifera (Rotaliida) and imperforate foraminifera (Miliolids, especially *Dendritina*). Fragments of Ostracods shells, Molluscs and Echinoderms are also seen in these microscopic facies. The different grains are in a micrite matrix. In some cases, as *Dendritina* decreases, the facies changes to rotaliid, miliolid wackestone/packstone. At times, Rotaliida and skeletal fragments make up the abundance of grains (Fig. 5i, j). The combination of fauna and stratigraphic status indicates lagoon microfacies and indicates that deposition in a lagoon shelf has occurred with normal rotation and oxygenated water (Romero et al., 2002). The presence of porcelain fauna in variable ratios with oval hyaline fauna related to sedimentation in the area, photic zone, lagoon open environment (Saeedi Razavi and Keshavarz, 2022; Pomar, 2001; Romero et al., 2002; Renema, 2006). A similar set of foraminifera by Vaziri-Moghaddam et al. (2006), and Sadeghi et al. (2010) in an open environment, lagoon is interpreted. The perforate and imperforate foraminifera assemblage is characteristic of an inner ramp sedimentary environment (Corda and Brandano, 2003). These microfacies are equivalent to RMF-13 Flügel (2010) and is attributed to the lagoon sedimentary environment. In the classification of Buxton and Pedley (1989), it is equivalent to the microfacies of the No. 2 facies belt.

4.14 Echinoid Packstone/Grainstone (MF14)

Echinoderm skeletal fragments are the most abundant grain in these microscopic facies. Fragments of molluscs and *Discorbis* (perforate foraminifera) are also found in small quantities. The granular texture is supportive (Fig. 6 a). In some sections, the texture of the rock changes to Corallinaceae echinoid packstone/grainstone. Accumulation of skeletal fragments of some organisms, including echinoderms, can lead to the formation of sand barriers (Wilson, 1975). The presence of stenohaline organisms such as echinoderm also indicates the association of these facies with the open seas (Heckel, 1977). These facies are the main part of the bioclastic barrier and is formed in a relatively high-energy environment.

4.15 *Amphistegina* bioclast Wackestone/Packstone (MF15)

The constituents of these facies are microscopic, *Amphistegina*, and skeletal fragments of bryozoans, echinoids, molluscs, and Corallinaceae. The above components, along with a percentage of planktonic foraminifera, are located in a micritic matrix (Fig. 6 b). Large benthic foraminifera such as *Amphistegina* and *Heterostegina* live in shallow water to the point of light penetration. They are abundant and dominant in oligophotic and mesophotic regions (Hottinger, 1997). The association of *Amphistegina* with the skeletal parts of stenohaline organisms and the background of the supporting mud indicates the subsidence of these facies in the shelf between the base level of waves in calm conditions and the base level of waves in stormy conditions (Flügel, 2004; Geel, 2000; Corda and Brandano, 2003).

4.16 *Operculina* bioclast Wackestone/Packstone (MF16)

Large benthic foraminifera (*Operculina* with thin-walled) and skeletal fragments of bryozoan, coral, and Corallinaceae are major components of this facies. These components are surrounded by micrite (Fig. 6 c, d, e, f). The lack of planktonic foraminifera and the increase and abundance of skeletal fragments and large perforate foraminifera indicate a decrease in depth. The set of these features indicates that these microfacies belongs to the shallower part of the slop. In some thin sections, the *Operculina* foraminifer is not observed and only the bioclasts of bryozoans, Corallinaceae, echinoids, and corals are present. These sections are part of these facies due to the type of bioclasts and their location in sequence with open marine facies (Flügel, 2004; Geel, 2000; Corda and Brandano, 2003). The rock texture in these facies is bioclast, wackestone/packstone, and sometimes flotestone.

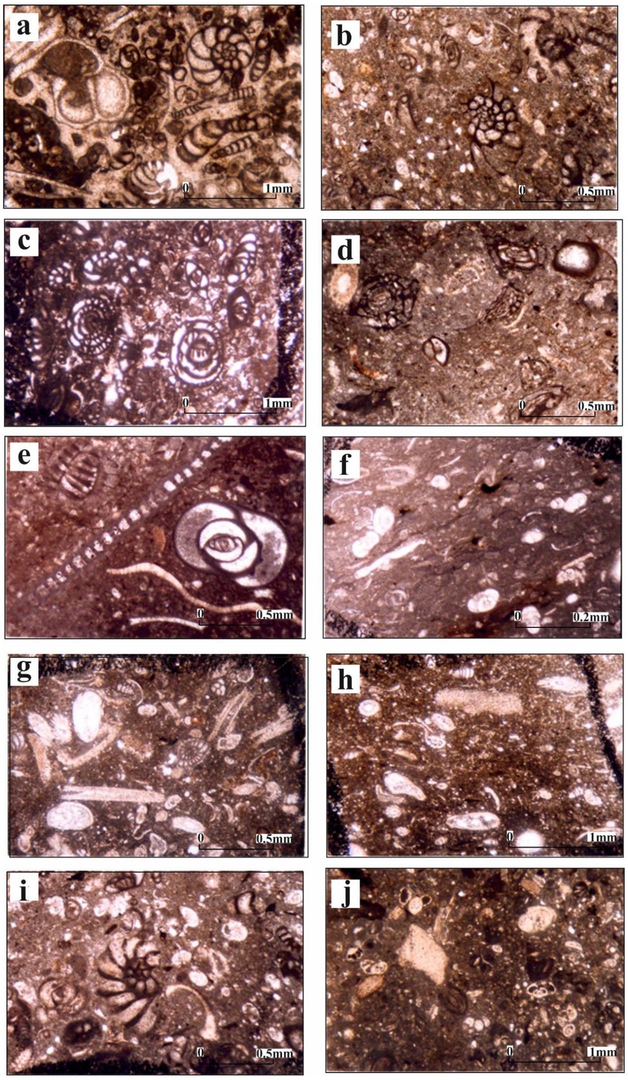

Figure 5. Microfacies of the Asmari Formation in the studied section. *Dendritina*, miliolid, biooclast packstone/-grainstone; (a), 25× magnification, *Dendritina* miliolid wackestone/packstone; (b), 40× magnification, *Dendritina*, *Borelis* miliolida packstone; (c), 25× magnification, miliolid, *Borelis* biooclast wackstone; (d), 40× magnification, *Borelis Meandropsina* miliolid bioclast wackestone/-packstone; (e), 40× magnification, Rotaliid bioclast wackestone/packstone; (f), 40× magnification, Rotaliid ostracod echinoid packstone; (g), 100× magnification, Rotaliid Ostracod bioclast wackestone; (h), 25× magnification, Rotaliid *Dendritina* miliolid wackestone/packstone; (i), 40× magnification, Rotaliid miliolid wackestone/packstone; (j), 25× magnification.

4.17 Pelagic foraminifera *Operculina* bioclast Wackestone/Packstone (MF17)

Skeletal fragments, echinoids, *Ditropa* (benthic foraminifera), bryozoans, large benthic foraminifera with a hyaline wall (*Operculina* and *Lepidocyclina*), and planktonic foraminifera form these facies. Small amounts of small benthic foraminifera and non-skeletal components such as destructive quartz are also observed. The above components are located in a micrite background. In these microfacies, pelagic foraminifers have less abundance than subsequent microfacies (Fig. 6 g, h). The decrease in the abundance of pelagic foraminifers and the presence of large benthic foraminifera that are dependent on light for life indicates the deposition of these facies in the shallower parts of the open marine. Large benthic perforate foraminifera such as *Operculina* and *Lepidocyclina* coexist with algae (symbiont bearing), so their association with heterotrophic organisms and planktonic foraminifera indicates the deepest part of the lower limit of the photic zone (Romero et al., 2002).

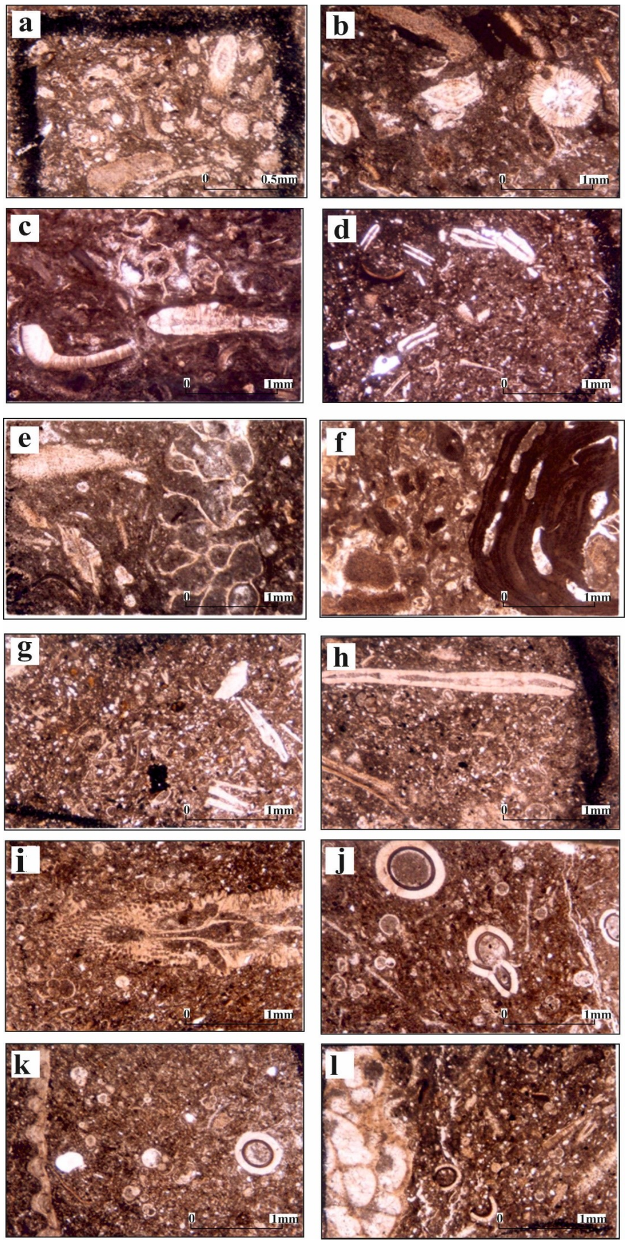

Figure 6. Microfacies of the Asmari Formation in the studied section. Echinoid packstone; (a), 40× magnification, *Amphistegina* bioclast packstone/wackestone; (b), 25× magnification, *Operculina* Bioclast packstone/wackestone; (c), 25× Magnification, *Operculina* Bioclast packstone/wackestone; (d), 25× Magnification, Bioclast wackestone; (e) 25× Magnification, Bioclast Corallinaceae packstone; (f), 25× Magnification, Pelagic foraminifera, *Operculina*, Bioclast packstone/wackestone; (g), 25× Magnification, *Operculina* Pelagic foraminifera Bioclast packstone/wackestone; (h), 25× Magnification, Pelagic foraminifera Bioclast packstone/wackestone; (i) (j) (k), 25× magnification, Pelagic foraminifera Bioclast packstone/wackestone; (l), 25× Magnification.

4.18 Pelagic foraminifera bioclast Wackestone/Packstone (MF18)

The most important skeletal components of these microfacies are pelagic foraminifers (*Globigerinoides*) and fragments of benthic organisms such as bryozoans, echinoids, bivalves, and *Ditropa* (benthic foraminifera). The grains are surrounded by a mud background. (allochems are floating in a micrite background.) Sometimes the amount of matrix is small and the rock texture is converted to packstone, but in most samples, the amount of matrix is more than 40% (Fig. 6 i, j, k, l). The abundance of planktonic foraminifera and their association with bryozoans, echinoids, and molluscs, which are heterotrophic organisms that do not need light to survive, indicate the deposition of these facies in the warm waters of the tropics area and below the photic zone. The background mud support and the lack of very large foraminifera indicate the formation of these facies below the effects of waves and low energy conditions of sea water (Romero et al., 2002). The location of these microscopic facies is comparable to belts 2 and 3 (Wilson, 1975) and slope area (Geel, 2000).

5. Sedimentary environment

Fossils, and sedimentary structures have been used to identify the facies and their environment. Lithofacial and biofacial properties indicate sedimentation of Asmari Formation limestones is a carbonate ramp (Flügel, 2010; Wilson, 1975; Read, 1985; Tucker, 1990; Burchette and Wright, 1992; Reading, 1996). Faunal aggregations (benthic foraminifera with imperforate wall and perforate wall) have played a major role in distinguishing the types of facies deposited in the carbonate shelf. Carbonate ramps can be divided into inner, middle, and outer ramps based on the arrangement of facies belts and the distribution of faunal assemblages. Large benthic foraminifers in shallow carbonate sequences in Permo-Carboniferous, Cretaceous, Tertiary, and present-day. In these facies are associated with ostracods, bryozoans, algae, bivalves, echinoids, gastropods, and corals.

Large benthic foraminifers, due to their optical symbiosis, their distribution and expansion are subject to light and are limited to the photic zone. Taxa are increasingly limited to depths of less than 60 meters. Temperature higher than 20° -22°, are necessary for their reproduction. The nature of the substrate, salinity, and energy of the environment are factors in the distribution of benthic foraminifera. The predominant taxa include miliolid, *Borelis*, *Peneroplis*, and with less abundance *Operculina*, *Lepidocyclina*, *Rotalia*, and *Amphistegina*.

In these sequences, benthic foraminifera with an imper-

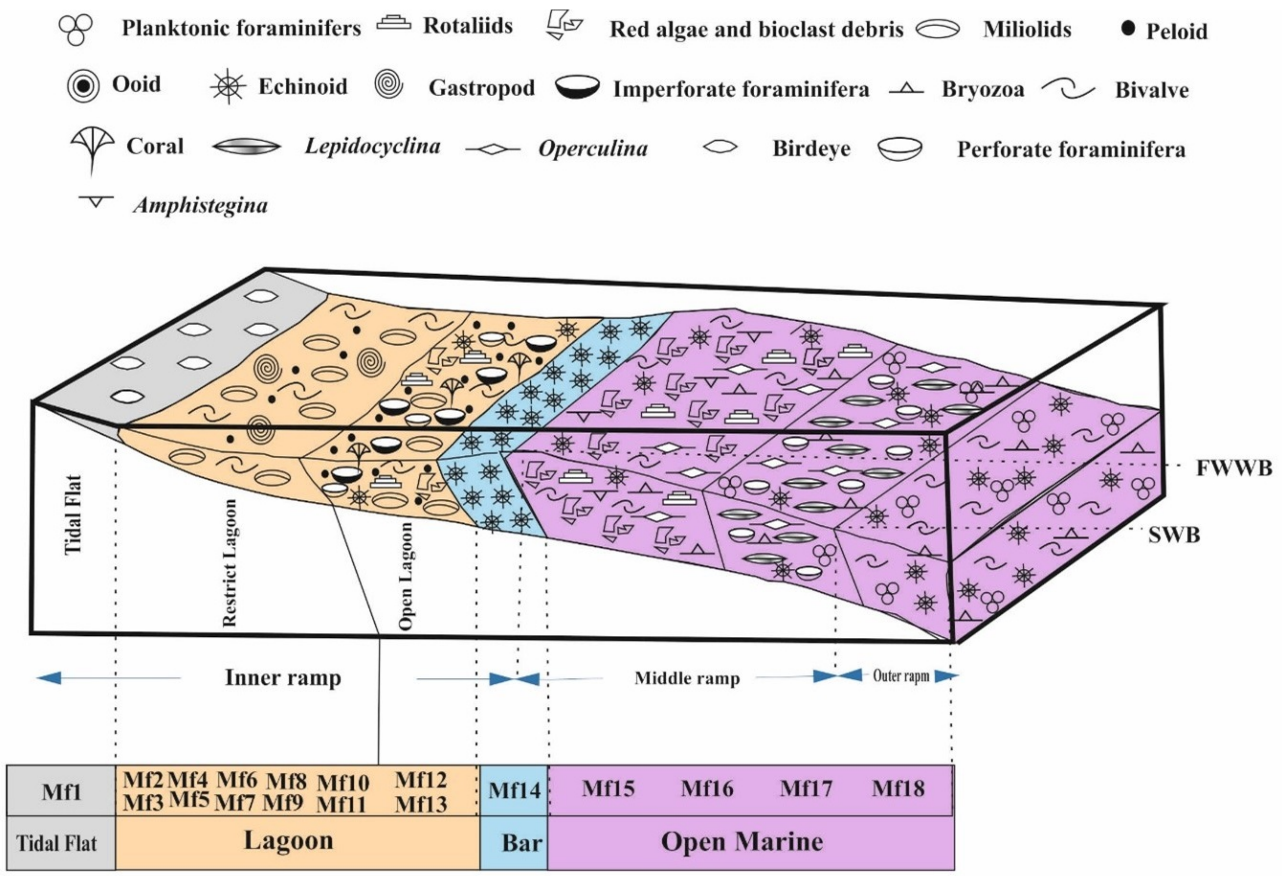

Figure 7. Sedimentary model of Asmari Formation in the studied section.

forate wall (porcelain) have a high frequency. Infers the expansion of the shallow platform. Based on the faunal assemblages, the shallow platform facies is divided into open and internal. The frequency of predominant accumulations of porcelain foraminifera indicates the soft bed in the restricted areas. In the open inner ramp, a mixture of open marine fauna and benthic foraminifera with an imperforate wall can be seen. The simultaneous emergence of offshore fauna and the inner shelf with each other indicates the absence of a continuous and extensive barrier that completely separates the inner shelf areas from the outer shelf. In this section, due to the circulation of water, salinity is relatively normal and species diversity is high. Mudstone facies with benthic fossils, due to the abundance of mud background and lack of diversity and abundance of fauna, indicate the deposition of sediments under the intertidal sub-environment, which are very shallow. Due to the intermediate nature of the tidal flat, its sediments are regularly or irregularly removed from the water and special structures have been created in them. These constructions include bird eye fabric and evaporative crystal mold. In the marginal part of the platform, due to favorable conditions, the accumulation of skeletal fragments has formed a barrier or discontinuous dams. Lack of biogenic structures and erosion of fossils indicate the action of waves and dispersion beds. Accumulation of skeletal parts of organisms, including echinoderms, can lead to the formation of washed sand deposits related to the barrier or dam. The lack of Oolite grains is attributed for lack of salinity in the sea, because these seeds need a more salinity to form. Due to the low slope and possibly the condition of the sea in terms of wave intensity (slow to moderate), barrier reefs have not been formed in this area. Accumulations of large benthic foraminifera with perforated walls (*Operculina*, etc.) and pelagic foraminifers at the base of the sequence represent open marine facies (Fig. 7).

6. Sequence stratigraphy

With the applications the principles and concepts of sequence stratigraphy, the carbonate succession divided into 3 complete sequences and 1 sequence (Fig. 8):

6.1 Sedimentary Sequence 1

This sequence began in the basal part with the open marine facies and gradually turns upwards into the shallow platform facies. The basal part was deposited during the increase of depth and gradual rise of sea level. The predominant fauna in these sediments is large benthic foraminifera with hyaline walls and elongated plate shells (mainly Operculina) and planktonic foraminifera. This section is considered as a progressive sediment category (TST: Transgressive System Tract). The rocks of the upper part of this sequence are deposited during the relative stillness and gradual lowering of the sea level and form the HST. The predominant fauna assemblage is benthic foraminifera with a perforated wall. Fallowing, the lowering of the sea level, the intertidal zone facies with fenestral fabric has been deposited. This sequence covers from the base up to 120 meters thick from

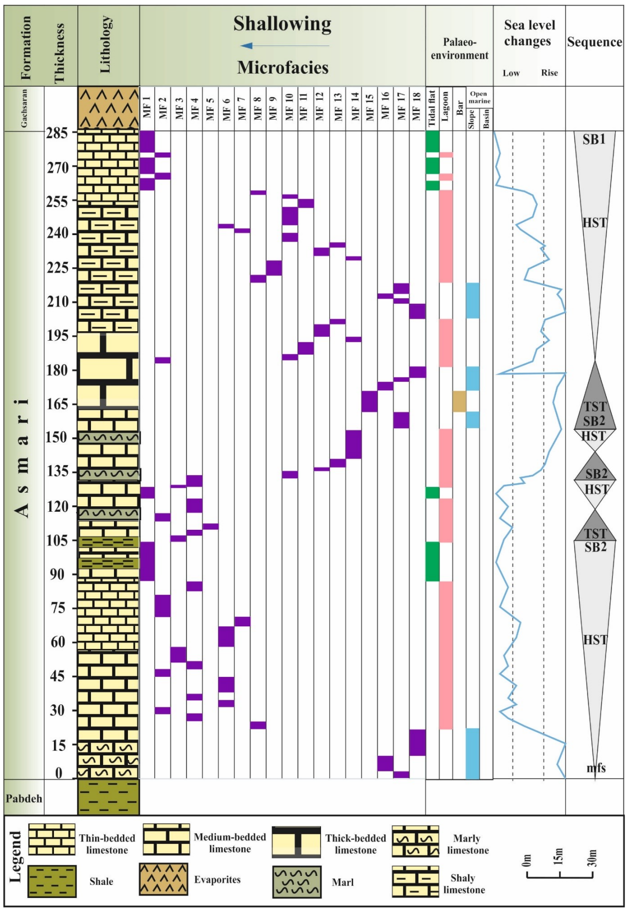

Figure 8. Vertical scattering diagram of microfacies and sequence stratigraphy of Asmari Formation of the studied section.

Asmari Formation.

6.2 Sequence 2

The sediment in this sequence is deposited in the inner ramp. Therefore, no specific textural and lithological changes are preserved that indicate the trend of shallow or deepening (Schlager 1981). The upper boundary of this sequence is characterized by the formation of the Mudstone facies with the fenestral fabric. The mentioned sequence is from 130 to 144 meters thick from Asmari Formation.

6.3 Sequence 3

This sequence is separated from the type 2 sequence boundary. The constituent facies are deposited in the inner ramp as in the 2 sequence. In some facies, the variety and frequency of fauna increase, which indicates their formation in the inner part of the ramp with free rotation. The boundary of this sequence ends with the subsidence of the quartz-bearing mudstone facies. The sequence is measures of 144 to 185 m thick from Asmari Formation.

6.4 Sequence 4

The boundary between this sequence and the 3 sequence is marked by a sudden facies change (Hillgärtner, 1998). Its base part (TST) consists of internal ramp facies and with gradual sea-level rise. These facies are replaced by middle ramp and slope facies. They are characterized by the abundance of the Corallinaceae, echinoid, bryozoan, and large benthic foraminifera with a hyaline wall. With the gradual decrease of the sea level and shallowing trend (HST), the facies of the inner ramp are deposited and terminates in the facies of the tidal flat (Mudstone with fenesteral fabric). The predominant fauna in the inner ramp facies consists of benthic foraminifera with an imperforate wall. This sequence is from 185 to 285 m thick (end of Asmari Formation).

7. Conclusion

- The distribution of skeletal parts (foraminifera, echinoid, bryozoan, Corallinaceae and molluscs, etc.) and non-skeletal parts (peloid) in different parts of the sedimentary basin, a total of 5 sub-environments were identified: Under the basin environment, the mudstone/wackestone foraminifera pelagic facies are predominant. In the slope environment of the basin different facies with the presence of large benthonic foraminifera with the hyaline wall, especially from two families of the Nummulitidae and Lepidocyclinidae (such as *Operculina*, *Heterostegina* and *Lepidocyclina*), as well as Rotaliida, red algae coralinacea, bryozoan, echinoid and fragmentary are recorded.
- The texture varies from wackestone to grainstone and floutestone and roadstone. The barrier environment is characterized by the presence of echinoid packstone, in which the water-energy is increased.
- The sub-environment Lagoon divided into under the semi-enclosed lagoon environment, offshore fauna association of lagoon fauna. The presence of hyaline-walled foraminifers with a relatively small size (relative to the open marine environment) such as *Rotalia*, along with perforate foraminifers such as *Borelis*, miliolid, indicates that it is a lagoon Aside, also Corallinaceae, Echinoids, and molluscs are in this environment.
- In the enclosed lagoon, imperforate foraminifera; miliolid and *Meandropsina*, along with Dasycladaceae algae and gastropods are present.
- The intertidal zone sub-environment is characterized by mudstone, bird's eye fabric, and sandy limestone. The identified sedimentary model is a carbonate ramp.
- Asmari Formation in this study consists of 3 complete sedimentary sequences and 1 incomplete sequence. These sequences are generally HST regressive and TST progressive in these sections. The HST regression facies category in this sequence began from marine microfacies and ends in lagoon facies. The TST progressive facies is related to the open marine. The regressive facies is related to the internal and middle platform and the progressive facies category is attributed to the external and intermediate platform.

Authors Contributions
All authors have contributed equally in preparing the paper.

Availability of Data and Materials
Data is available on request from the authors. The data supporting this study's findings are available from the corresponding author, upon reasonable request.

Conflict of Interests
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.

References

Abyat Y., Abyat A., Abyat A. (2019) Microfacies and depositional environment of Asmari formation in the Zeloi oil field, Zagros basin, south-west Iran. *Carbonates and Evaporites* 34 (4): 1583–1593.

Aghanabati A. (2006) Geology of Iran. *Geological Survey of Iran, Tehran* 586 In Persian

Alavi M. (2004) Regional stratigraphy of the Zagros fold-thrust belt of Iran and its proforeland evolution. *American Journal of Science* 304:1–20.

Allahkarampour M., Seyrafian M. A., Vaziri-Moghaddam H. (2012) Paleoecology of the Oligocene–Miocene Asmari Formation in the Dill anticline (Zagros Basin, Iran). *N Jb Geol Paläont, Abh* 263 (2): 167–184.

——— (2010) The Asmari Formation, north of the Gachsaran (Dill anticline), southwest Iran, facies analysis, depositional environments and sequence stratigraphy. *Carbonates and Evaporites* 25:145–160.

Amirshahkarami M. (2013) Microfacies correlation analysis of the OligoceneeMiocene Asmari Formation, in the central part of the Rag-e-Safid anticlinal oil field, Zagros Basin, south-west Iran. *Turkish Journal of Earth Science* 22:204–219.

Amirshahkarami M., Vaziri-Moghaddam H., Taheri A. (2007a) Paleoenvironmental model and sequence stratigraphy of the Asmari Formation in southwest Iran. *Historical Biology* 19 (2): 173–183.

——— (2007b) Sedimentary facies and sequence stratigraphy of the Asmari Formation at Chaman-Bolbol, Zagros Basin, Iran. *Journal of Asian Earth Science* 29:947–959.

Avarjani S., Mahboubi A., Moussavi-Harami R., Amiri-Bakhtiar H., L. Brenner R. (2015) Facies, depositional sequences, and biostratigraphy of the Oligo-Miocene Asmari Formation in Marun oilfield, North Dezful Embayment, Zagros Basin, SW Iran. *Palaeoworld* 24:336–358.

Bahroudi A., Koyi H. A. (2004) Tectono-Sedimentary Framework of the Gachsaran Formation in the Zagros Foreland Basin. *Marine and Petroleum Geology* 21:1295–1310.

Bassi D., Hottinger L., Nebelsick H. (2007) Larger Foraminifera from the Upper Oligocene of the Venetian area, northeast Italy. *Palaeontology* 5 (4): 845–868.

Berberian M., King G. C. P. (1981) Towards a paleogeography and tectonic evolution of Iran. *Canadian Journal of Earth Science* 18:210–265.

Brandano M., Frezza V., Tomassetti L., Pedley M. (2009) Facies analysis and paleoenvironmental interpretation of the Late Oligocene Attard Member (Lower Coralline Limestone Formation), Malta. *Palaeogeography, Palaeoclimatology, Palaeoecology* 274:54–63.

Burchette T. P., Wright V. P. (1992) Carbonate ramp depositional systems. *Sediment Geology* 79:3 –57.

Buxton M. W. N., Pedley H. M. (1989) A standardized model for Tethyan Tertiary carbonate ramps. *Journal of the Geological Society, London* 146:746–748.

Corda L., Brandano M. (2003) Aphotic zone carbonate production on a Miocene ramp, Central Apennines, Italy. *Sedimentary Geology* 161:55–70.

Dehghanian M. (2017) Microfacies study of Oligo-Miocene in SE Norabad in Fars Province. *1st National Conference on Modern Applied Research of Basic Sciences* 1:43–51.

Dunham R. J. (1962) Classification of carbonate rocks according to depositional texture. *American Association of Petroleum Geologists Bulletin* 1:108–121.

Embry A. F., Klovan J. E. (1971) Alate Devonian reef tract on north eastern Banks Island, NWT. *Bulletin of Canadian Petroleum Geology* 19:730–781.

Emery D., Myers K. J. (1996) Sequence Stratigraphy, Blackwell Science, *Oxfordp*, 297 p.

Falcon N. L. (1961) Major earth-flexuring in the Zagros Mountain of southwest Iran. *Journal of the Geological Society.* 117:367–376. London

Flügel E. (2010) Microfacies analysis of limestone: interpretation and application. *Springer-Verlag,* 976 p. Berlin

——— (2004) Microfacies data: fabrics. Microfacies of carbonate rocks: analysis, interpretation and application. *Springer-Verlag.,* 177–242.

Geel T. (2000) Recognition of stratigraphic sequence in carbonate platform and slope, empirical models based on microfacies analysis of Paleogene deposits in southeastern Spain. *Palaeogeography, Palaeoclimatology, Palaeoecology* 155 (3): 211–238.

Haq B. U. J., Hardenbol P., Vail R. (1987) Chronology of fluctuating sea level since the Triassic. *Science* 235:1156–1167.

Hatefi S. M., Seyrafian A., Vaziri-Moghaddam H., Rahmani A., Perrin C. (2018) Biostratigraphy, microfacies and paleoecology of the Asmari Formation, Interior Fars province, Zagros Basin, Iran. *N. Jb. Geol. Paleont. Abh* 288 (1): 87–105.

Heckel P. H. (1977) Origin phosphatic black shale facies in Pennsylvanian cyclotherms of Midcontinent North America. *American Association of Petroleum Geologists Bulletin* 61:1045–1068.

Heydari E., Hassanzadeh J., Wade W. J., Ghazi A. M. (2003) Permian– Triassic boundary interval in the Abadeh section of Iran with implications for mass extinction, Part 1-Sedimentology. *Paleogeography, Paleoclimatology, Paleoecology* 193 (3): 405–423.

Hillgärtner H. (1998) Discontinuity surfaces on a shallow-marine carbonate platform (Berriasian, Valanginian, France and Switzerland). *Journal of Sedimentary Research* 68:1093–1108.

Hottinger L. (1997) Shallow benethic foraminiferal assembelages as signals for depth of their deposition and their limitations. *Bulletin de la Société Géologique de France* 168:491–505.

James G. A., Wynd J. G. (1965) Stratigraphic nomenclature of Iranian oil consortium agreememt Area. *American Association of Petroleum Geologists Bulletin* 49:2182–2245.

Kangazian A., Pasandideh M. (2016) Sedimentary Environment and Sequence Stratigraphy of the Asmari Formation at Khaviz Anticline, Zagros Mountains, Southwest Iran. *Open Journal of Geology* 6:87–102.

Karami S., Ahmadi V., Sarooe H. (2020) Facies analysis and depositional environment of the Oligocene–Miocene Asmari Formation, in Interior Fars (Zagros Basin, Iran). *Carbonates and Evaporites* 35 (1): 1722–1737.

Mirzaee-Mahmoodabadi R. (2014) Petrography, Sedimentary Environments and Sequence Stratigraphy of Asmari Formation in Central Fars, Zagros, SW (Iran). *Open Journal of Geology* 4 (12): 665–679.

Monjezi N., Mahnaz Amirshahkarami M., Amiri Bakhtiar H., Parvaneh Nejad Shirazi M., Mirzaee A. (2019) Palaeoecology and microfacies correlation analysis of the Oligocene–Miocene Asmari formation, in the Gachsaran oil field, Dezful Embayment, Zagros Basin, Southwest Iran. *Carbonates and Evaporites* 34:1551–1568.

Mossadegh Z. K., Haig D. W., Allan T., Adabi M. H., Sadeghi A. (2009) Salinity changes during Late Oligocene to Early Miocene Asmari Formation deposition, Zagros Mountains, Iran. *Palaeogeography, Palaeoclimatology, Palaeoecology* 272:17–36.

Motiei H. (1993) Stratigraphy of Zagros. *Geological Survey of Iran Publication, Tehran.,* 536 p.

Pomar L. (2001) Ecological control of sedimentary accomodation: Evolution from a carbonate ramp to rimmed shelf, Upper Miocene, Balearic Island. *Palaeogeography, Palaeoclimatology, Palaeoecology* 175:249–272.

Rajabi M., Senemari S., Parvaneh Nejad Shirazi M., Bahrammanesh Tehrani M. (2021) Depositional environment and microfacies analysis: An example of the Asmari Formation in West Zagros Basin, Lorestan province (Iran). *Iranian Journal of Earth Sciences* 13 (2): 94–114.

Read J. F. (1985) Carbonate platform facies models. *American Association of Petroleum Geologists Bulletin* 69:1–21.

Reading H. G. (1996) Sedimentary environments and facies. *Blackwell Scientific Publication,* 425 p.

Reiss Z., Hottinger L. (1984) The Gulf of Aqaba: Ecological Micropaleontology. Springer, Berlin. *Carbonates Evaporites* 25:145–160.

Renema W. (2006) Large benthic foraminifera from the deep photic zone of a mixed siliciclastic-carbonate shelf off East Kalimantan, Indonesia. *Marine Micropaleontology* 58:73 – 82.

Romero J., Caus E., Rosell J. (2002) A model for the palaeoenvironmental distribution of larger foraminifera based on late Middle Eocene deposits on the margin of the South Pyrenean basin (NE Spain). *Palaeogeography, Palaeoclimatology, Palaeoecology* 179 (1): 43–56.

Sadeghi R., Vaziri-Moghaddam H., Taheri A. (2010) Microfacies and sedimentary environment of the Oligocene sequence (Asmari Formation) in Fars sub-basin, Zagros Mountains, southwest Iran. *Facies* 57:431–446.

Saeedi Razavi B. (2021) Biostratigraphy, Paleoecology, Microfacies and Depositional environment of the Asmari formation (Oligocene-Early Miocene) in Karanj oil field, SW Iran. *Iranian Journal of Earth Sciences* 13 (3): 181–195.

Saeedi Razavi B., Keshavarz M. T. (2022) Biostratigraphy and facies analysis of the Asmari Formation in the north of Gachsaran (mish anticline), southwestern Iran. *Carbonates and Evaporites, in press.*

Sahraeyan M., Bahrami M., Arzaghi S. (2014) Retracted Facies analysis and depositional environments of the Oligocene–Miocene Asmari Formation, Zagros Basin, Iran. *Geoscience Frontiers* 5 (1): 103–112.

Seyrafian A. (2000) Microfacies and depositional environment of the Asmari Formation at Dehdez area. *Carbonates and Evaporites* 15:121 –130.

Seyrafian A., Hamedani A. (2003) Microfacies and paleoenvironmental interpretations of the Lower Asmari Formation (Oligocene), north-central Zagros Basin, Iran. *Neues Jahrbuch für Geologie und Paläontologie Monatshefte* 3:164 –174.

Seyrafian A., Vaziri-Moghaddam H., Arzani N., Taheri A. (2011) Facies analysis of the Asmari Formation in central and north-central Zagros basin, southwest Iran. *Biostratigr, Paleoecol Diagenes* 28:439–458.

Shabafrooz R., Mahboubi A., Vaziri-Moghaddam H., Ghabeishavi A., Moussavi-Harami R. (2015) Depositional architecture and sequence stratigraphy of the Oligo-Miocene Asmari platform; Southeastern Izeh Zone, Zagros Basin, Iran. *Facies* 61 (1): 1–32.

Simmons M. D., Sharland P. R., Casey D. M., Davies R. B., Sutcliffe O. E. (2007) Arabian Plate sequence stratigraphy, Potential implications for global chronostratigraphy. *GeoArabia* 12 (4): 101–130.

Sooltanian N., Seyrafian A., Vaziri-Moghaddam H. (2011) Biostratigraphy and paleo-ecological implications in microfacies of the Asmari Formation (Oligocene), Naura anticline (Interior Fars of the Zagros Basin), Iran. *Carbonates and Evaporites* 26:167–180.

Stocklin J. (1968) Structural History and Tectonic of Iran: A Review. *American Association of Petroleum Geologists Bulletin, USA* 52:1229–1258.

Tucker M. E. (1990) Geological background to carbonate sedimentation. In: Carbonate Sedimentology (Ed. by M.E. Tucker & V.P. Wright). *Blackwell Scientifc Publications, Oxford,* 482 p.

Van-Wagoner J. C., Posamentier W., Mitchum H. R. M., Vail P. R., Sarg J. F., Loutit T. S., Hardenbol J. (1988) An Overview of the fundamentals of sequence stratigraphy and key definitions. In Sea Level Changes–An Integrated Approach C. K. Wilgus, B. S. Hastings,-C. G. St. C. Kendall, H. W. Posamentier, C. A. Ross and J. C. Van Wagoner, Eds.). *SEPM Special Publication* 42:39–45.

Vaziri-Moghaddam H., Kimiagari M., Taheri A. (2006) Depositional environment and sequence stratigraphy of the Oligo-Miocene Asmari Formation is SW Iran. *Facies* 52:41–51.

Vaziri-Moghaddam H., Seyrafian A., Taheri A. (2010) Oligocene-Miocene ramp system (Asmari Formation) in the NW of the Zagros basin, Iran: microfacies, paleoenvironment and depositional sequence. *Revista Mexicana de Ciencias Geológicas* 27:56–71.

Wilson J. L. (1975) Carbonate facies in geologic history. *New York: Springer-Verlag.,* 471 pp.

Yazdani R. (2014) Biostratigraphy and Facies Distribution of The Asmari Formation in Aghajari Well#66, Zagros Basin, SW Iran. *International Research Journal of Geology and Mining (IRJGM)* 4:101–115.