Facies Distribution, Paleoecology and Sedimentary Environment of the Oligocene-Miocene (Asmari Formation) deposits, in Qeshm Island, SE Persian Gulf

1Seyed Hadi Sajadi, 2Darioush Baghbani, 3Jahanbakhsh Daneshian

1Department of Geology, North Tehran Branch, Islamic Azad University, Tehran, Iran
2Department of Geology, Damavand University, Tehran, Iran
3Department of Geology, Earth Sciences Faculty, Kharazmi University, Tehran, Iran

ABSTRACT

This research is focused on facies distribution, paleoecology and palaeoenvironment of the Asmari Formation at the Qeshm Island, Southeast Persian Gulf. The Asmari Formation is composed of limestone, marly limestone and marl. The subsurface data is indicated the thickness of the Asmari succession is about 148 meters and two assemblage zones have been recognized by distribution of these large foraminifera in the study area that indicate latest Oligocene (Chattian)–early Miocene (Aquitanian) age. Because of gradual facies changes and absence of turbidite deposits indicate that the Asmari Formation was deposited in a carbonate ramp environment. Based on depositional textures, petrographical studies and fauna of 60 thin sections, seven microfacies have been identified and characterizing upward gradual shallowing trend of another ramp. MF1 was characterized by the occurrence of hyaline benthic and planktonic foraminifera representing distal middle ramp and below the storm wave base of other ramp. MF2 with large and small hyaline benthic foraminifera represent a deeper fair water wave base of a middle ramp setting. MF3–6 were characterized by the occurrence of large and small porcellaneous benthic foraminifera representing a shallow-water setting of an inner ramp influenced by wave and tide processes. Palaeolatitudinal reconstructions based on skeletal grains suggest that carbonate sedimentation of the Asmari Formation took place in tropical waters within photic zone.

INTRODUCTION

This paper deals with the Asmari Formation (one of the best known carbonate reservoirs in the world) [68], an Oligocene-Miocene carbonate succession in the southeastern Zagros basin, southern Iran (Fig. 1). At the type section in Tang-e Gel-e Tursk (Valley of Sour Earth) on the southwestern flank of the Kuh-e Asmari anticline, the Asmari Formation consists of 314 m of mainly limestones, dolomitic limestones, and argillaceous limestones [44,45]. In the Qeshm Island, the Asmari shallow-marine limestone is located in the subsurface and was deposited over the Pabdeh Formation gradational. The contact with the overlying Gachsaran Formation (i.e., evaporates rocks) is conformable and gradual (Fig. 3). This formation is present in most of the Zagros basin and lithologically, consists of limestone, dolomitic limestone, dolomite and marly limestone. Some anhydrite (Kalhur Member) and lithic and limy sandstones (Ahwaz Member) also occur within the Asmari Formation [44,45]. The previous studies have focused on biostratigraphy and lithostratigraphy of the Asmari Formation and was originally defined in primary works by [18,54,64,63]. Later, [40,70,39] introduced the microfaunal characteristics and assemblage zones for the Asmari Formation. More recent studies of the Asmari Formation have been conducted on facies and sedimentary environment [66,5,6252,4,58,61,65]. This paper reports in the subsurface sedimentological study of Asmari Formation, whose results could correlate and compare to a better understanding of the outcrops Asmari Formation in adjacent areas. The objectives of this study are (1) a description of the facies and their distribution on the Oligocene-Miocene carbonate platform and (2) interpretation of the paleoenvironment features based on the assemblages of benthic hyaline and imperforate
foraminifera. In this article one stratigraphic subsurface section was chosen and subjected to detailed microfacies analysis based mainly on the distribution of Oligo-Miocene foraminiferal assemblages.

![Stratigraphic Correlation Chart](image1)

**Fig. 1:** Cenozoic stratigraphic correlation chart of the Iranian sector of the Zagros Basin, adopted from (James and Wynd 1965).

![Map of Iran and Zagros Basin](image2)

**Fig 2:** (A) General map of Iran showing the Zagros province (B) Structural of Zagros Basin [2] (C) Location map of the studied section modified after [31](Geological Division 2004).

**Geological Setting:**

The Zagros Basin is the second largest basin in the Middle East and defined by a 7–14 km thick succession of cover sediments deposited over a region along the north–northeast edge of the Arabian plate. This basin was part of the stable Gondwana supercontinent in the Paleozoic era and a passive margin in the Mesozoic era and it became a site of convergent orogeny in the Cenozoic era [7]. The Zagros Fold-and-Thrust Belt of Iran is a result of the Alpine orogenic events[55,57] in the Alpine–Himalayan mountain range. It extends in a NW–SE direction from eastern Turkey to the strait of Hormoz in southern Iran. The tectonic activity of this area was
entirely due to converging of the Arabian and Eurasian continents. After the closure of the Neo-Tethys basin, during late Oligocene-early Miocene times the Zagros basin was gradually narrowed and the Asmari Formation was deposited with lithology, including lithic sandstone (Ahwaz Member) and evaporites (Kalhur Member) [3,68]. The maximum thickness of the Asmari Formation is found in the northeastern corner of the Dezful Embayment. On the basis of lateral facies variations, the Iranian Zagros fold-thrust belt is divided into different tectonostratigraphic domains that are from SE to NW: the Fars Province or eastern Zagros, the Khuzestan province or Central Zagros and finally the Lurestan Province or Western Zagros [44,45] (Fig. 2B). Also, from southwest to northeast of the Zagros basin are the Zagros folded belt, folded and thrust belt and High Zagros and crush zone [26,59,60, 25]. Hormozgan province is located in southern Iran and is part of Zagros Folded belt. This region is accompanied by NW-SE, W-E and N-S trending simple anticlines and synclines with very great thickness of Fars Group deposits (Gachsaran, Mishan, Aghajari and Bakhtiar formations) and presence of 118 salt plugs. So, for these specific features, [44,45] called this area as the “Bandar Abbas Hinterland” (Fig. 2).

Methods and Study Area:
This study involves one stratigraphic subsurface section from the Asmari Formation. The study area is located at Qeshm Island, southern Iran (Fig. 2C). The lithologies and the microfacies types were classified and described according to [23]. Some samples from the underlying Pabdeh and overlying Gachsaran formations were also analyzed for boundaries distinction. A total of 60 thin sections of the cores and cuttings are analyzed under the microscope for biostratigraphy and facies. Petrographic studies were carried out for facies analysis and paleoenvironmental reconstruction of the Asmari Formation. Facies were determined for each paleoenvironment according to carbonate grain types, textures and interpretation of functional morphology of small and larger foraminifers. Biostratigraphy are determined based on the well-known benthic foraminifera biozones of [1].

Result:
Biostratigraphy:
Biostratigraphic criteria of the Asmari Formation were established by [70] and reviewed by [1] in unpublished reports only. Biozonation and age determinations in the study area are based on benthic foraminifera biozonation of (Adams and Bourgeois 1967). From base to top, two foraminiferal assemblages were recognized and were discussed in ascending stratigraphic order as follows:


Assemblage II. This assemblage corresponds to the Miogypsinoide-Idarchaias - Valvulinid sp. 1 Assemblage Zone (2) of [1]. The assemblage is considered to be Aquitanian in age and The most important foraminifera in this assemblage are Miliolids gen. et sp. Indet., Peneroplis evolutus, Archaiaas sp., Peneroplis sp., Operculina spp., Peneroplis thomasi, Austroccina asmariensis, Reussella sp., Dendritina rangi, Elphidium sp. 1, Spirocynthia sp., Quinqueloculina sp., Archaias kirkukensis.

Microfacies Analysis:
Facies analysis of the Asmari Formation in the study areas resulted in the definition of seven facies types which characterize platform development. Each of the microfacies exhibits typical skeletal and non-skeletal components and textures. These facies are related to the three depositional settings (lagoon, barrier, and open marine) of inner, middle and outer portions of a carbonate platform (Fig. 5). Since Asmari Formation in the study area overlies the Pabdeh and underlies the Gachsaran formations conformably, some samples from Pabdeh and Gachsaran formations have been studied too. The general environmental interpretations of the microfacies are discussed in the following paragraphs.

MF 1. Marl facies (Fig. 6A-D):
There are intercalations of marl across the section but mainly this facies occurs in the lower parts of the succession. They are gray to green and contain benthic (miliolids, Nummulites, Neorotalia, Elphidium, Operculina, Amphistegina and textularids) and planktonic (Paragloborotalia mayeri and Globigerina spp.) foraminifera. The planktonic foraminifera occurrence of the base of succession, where is the boundary between Pabdeh and Asmari formations [51].
Interpretation:
The feature of benthic fauna and stratigraphic relationships with the other microfacies suggest that marl facies were deposited in an open lagoon, calm, deep and normal-salinity water but the co-occurrence of planktonic and some benthic (Nummulitidae) foraminifera in the base of the Asmari marl and marly limestone, suggest that this facies was deposited in calm, low energy hydrodynamic and deep normal salinity water which indicates deposition below the storm wave base [69,19,22,28]

MF.2. Bioclast lepidocyclinidae, nummulitidae, Neorotalia, wackstone-packstone (Fig. 6/E-G):
This microfacies is composed of grain-supported texture with abundant larger benthic foraminifera. The foraminiferal assemblage is represented by numerous larger benthic perforate foraminifera such as lepidocyclinidae and nummulitidae (Nummulites and Operculina). Other components such as Astrigerina and red algae are rare. Due to changes in the type of fauna in some samples, the name of this facies changes to bioclast, lepidocyclinidae, nummulitidae, Neorotalia wackstone-packstone. biostratigraphy distribution and Paleoenvironmental model of the Asmari Formation in this interval is most prominent in the lower parts of the Asmari Formation Iran [5].

Interpretation:
It consists of grey marly limestone beds. The combination of micritic matrix and abundance of typical open-marine fauna including large Nummulitidae, Lepidocyclinidae and Neorotalia suggest low–medium energy, open-marine environment. Other bioclasts such as red algae and shell fragments are rare. This microfacies show an environment between the storm wave base and fair-weather wave base [69,28]. The presence of large nummulites and lepidocyclids represents that this microfacies took place in relatively deep water and was formed in the lower photic/oligophotic zone in the distal middle ramp [35,36,43,53,33,32,30,50,56,11,48,9,10,57].

MF.3. Coral boundstone (Fig. 6/H-I):
This facies is characterized by the abundance of scleractinian and massive coral colonies.

Interpretation:
This microfacies is interpreted to be formed by in-situ organisms as an organic reef (Bioherm) in margin of platform and was located above the fair-weather wave base (FWWB)[69].

MF.4. Miliolids corallinacea bioclastic wackestone (Fig. 6/J-K):
Miliolids, corallinacea red algae and coral are dominating components in this microfacies. Other bioclasts are rare but include Peneroplis and dendritia fragments. The textures are wackestone.

Interpretation:
The MF4 and MF5 represent low to medium-energy open lagoon shallow subtidal environments, but there is different from them by their texture and grain composition. Depositional textures, fauna and stratigraphic position may have taken place in warm, euphotic and shallow water, with low to moderate energy conditions, in a semi-restricted lagoon. This area is located within inner carbonate platform setting [51]. The presence of well-preserved coralline algal indicates a relatively quiet-water environment with stable substrate and low sedimentation rates [47]. The associations of miliolids within this facies support the additional interpretation of a relatively protected environment, probably the inner part of a platform [29].

MF.5. Miliolids bioclastic wackestone (Fig. 6/L-M):
This facies is characterized by the dominant presence of small benthic foraminifera (miliolids). Other components such as Peneroplids, Elphidium, Bryozoan and excentract are rare. The matrix is fine grained micrite.

Interpretation:
This facies characterized by low diversity skeletal fauna and was deposited in restricted low energy lagoonal environments. There is a low biotic diversity of fauna which shows a high-stressed habitat in very shallow restricted areas, where great fluctuations in salinity and temperature probably occurred [51].

MF.6. Imperforate foraminifera bioclast wackestone-packstone (Fig. 6/N-O):
The main elements of this microfacies are skeletal and non-skeletal components. The skeletal components include high diversity of imperforate foraminifera in grain-supported textures and several genera of benthic foraminifera (Austrotetrillina, Archaias, Peneroplis, Meandropsina, Elphidium, Dendritina and miliolids), peloid are rare non-skeletal associations. The other minor biota consists of particles of bryozoans and coral.
Fig. 3: Lithostratigraphy column, microfacies, benthic and planktonic foraminifers’ distribution and biozonation of the Asmari Formation at Qeshm Island (Well no. 2).

**Interpretation:**

The occurrence of large number of porcelaneous imperforate foraminiferal tests may point to the depositional environment being slightly hyper-saline [65]. These deposits include different textures ranging from wackestone to packstone. Some porcelaneous imperforate foraminiferal (*Peneroplis* and *Archaias*) live in recent tropical and subtropical shallow water environments [13]. Textural characteristics and prolific porcelaneous foraminifera, suggest that a medium to high energy portion of a restricted lagoon with a nearby tidal flat sedimentary environment prevailed and shallow marine environments [67]. Such an assemblage described to be associated with an inner ramp environment [69,27,28,67,13,68].

**MF.7. Evaporate (Fig. 6/P):**

Anhydrite and gypsum facies have been observed in the upper part of the Asmari Formation which is represents the beginning of the Gachsaran Formation. The first anhydrite has been deposited above the marly limestones with a sharp contact.

**Interpretation:**

Considering the deposition of anhydrite implicates that the depositional environment became isolated from the open marine at that time, which allowed for the concentration and submarine precipitation of salt. The thickness of the evaporated deposits indicates that they are submarine deposits formed in an isolated saline basin. A eustatic sea level drop is one of the most likely causes. This event took place around the early Miocene (Aquitanian) and in the boundary of the Asmari and Gachsaran formations. But based on [24] this anhydrite is
exposed on top of the Asmari Formation and indicate the Oligocene-Miocene boundary. [24] noted that strontium dates got from anhydrite formed as an evaporate rather than as a later diagenetic product.

Fig. 4: Foraminifera and non-foraminifera distribution of the Oligocene deposits, adopted from joint project of French and Iran oil company (IFP-INOP 2006)

Discussion:

Sedimentary development of the Oligocene-Miocene Fars sub-basin:

During the Paleogene Pabdeh (basinal marls and argillaceous limestones) Formation were deposited in the middle and on both sides of the Zagros basin axial [44] (Fig. 1). The shallow-marine limestones of the Asmari Formation were deposited above the Pabdeh Formation in the section of this study (Fig. 1). During the Rupelian and early Chattian, outer ramp facies (Pabdeh Formation) was predominant at the Qeshm section (well no. 3) (Fig. 3). This is visible in the lower part of the Asmari Formation. So, the Chattian sediments of the Asmari Formation in this section overlie gradationally the Pabdeh Formation. Restricted shallow subtidal environments
are observed during Chattian times and indicated by an assemblage of abundant perforate benthic foraminifera.

**Fig. 5:** Depositional model for the carbonate platform of the Asmari Formation at the southeast of Zagros basin, Qeshm Island. Interpretation adopted from [37].

**Paleoecology:**

Large benthic foraminifera (such as Nummulitidae) produced great amount of carbonates during the Early and Middle Paleogene. In the Oligocene, euphotic conditions prevailed and carbonate production related to these foraminifers (especially Nummulites) declined [49]. Larger perforate forms are represented by Amphistegina, nummulitids and lepidocyclinids. Perforate foraminifera that live in shallow waters are characterized by hyaline walls and so protect themselves from ultra violet light by producing very thick, lamellate test walls to prevent photo inhibition of symbiotic algae within the test in bright sunlight. These large forms are the most important indicators for constructing paleo-environmental models in the warm, shallow marine environments [30]. The presence of these large and flat forms (lepidocyclinidae and nummulitidae) in the lower part of Asmari Formation, in comparison with analogues in the modern platform allowed interpreting these sediments as having been deposited in the lower photic zone [35,36,43,53,33,32]. In contrast, coralline red algae communities become dominant, as most phototrophic carbonate producers thrive in shallow marine environments [49], especially through Early Miocene to Tortonian [14]. Coralline red algae and large benthic foraminifera (*Nummulites*, *Opectulina*, *Lepidocyclina*, *Archaias*, *Peneroplis* and *Dendritina*) are the most significant and dominant biota in the Asmari Formation at the study area. Other components such as corals, bryozoan and echinoderms are present within the matrix. The distribution of larger foraminifera and coralline red algae are largely depended on the salinity, depth, light, temperature and climate, nutrients, effect of hydrodynamic energy and flows substrate on the biostratigraphic and dispersion of taxa [46,61]. Small benthic foraminifera are common locally and include porcelaneous (miliolids) and perforated (rotaulids) forms. Rotaliids are dominated by *Neorotalia viennoti* specimens. Larger foraminifera are represented by the porcelaneous imperforate tests such as *Archaias* and *Peneroplis* may point to the depositional environment being within the photic zone in tropical carbonate platforms and slightly hypersaline [69,27,28,67]. Flatter tests and thinner test walls with increasing water depth reflect decreased light levels at greater depths or perhaps poor water transparency in shallow waters [11]. These test shapes reflect adaptation to low hydrodynamic energy. Some biogenic components such as miliolids indicate stress conditions within restricted environments. Miliolids-dominant benthic foraminifer assemblages reflect decreased circulation and probably reduced oxygen contents or euryhaline conditions. Miliolids are found in a variety of very shallow, hyposaline to hypersaline environments, or are even common in the sand shoal environments of normal salinities [15,16] and are generally taken as evidence of restricted lagoon [51].

**Depositional Environment:**

Three depositional environments are identified in the Oligocene-Miocene succession in the Qeshm Island,
on the basis of the distribution of the foraminifera, non-foraminifera and vertical facies relationships (Fig. 4). These include lagoon, barrier, and open marine (Fig. 5).

![Microfacies types of the Asmari Formation.](image)

**Fig. 5:** Microfacies types of the Asmari Formation. (A-D) MF. 1, Marl facies. (E-G) MF. 2, Bioclast lepidocyclinidae, nummulitidae, *Neorotalia*, wackstone-packstone. (H-I) MF. 3 Coral boundstone. (J-K) MF. 4, Miliolids corallinacea bioclastic wackestone. (L-M) MF. 5, Miliolids bioclastic wackestone. (N-O) MF. 6, Imperforate foraminifera bioclast wackestone-packstone. (P) MF7, Evaporate.

These three environments are represented by seven microfacies types (MF1: distal middle ramp and below the storm wave base of other ramp, MF2: deeper fair water wave base of a middle ramp setting and MF 3–6: shallow-water setting of an inner ramp influenced by wave and tide processes). Carbonate ramp environments
are characterized by: (1) the inner ramp, between the upper shore face and fair weather wave base, (2) the middle ramp, between fair weather wave base and storm-wave base, and (3) the outer ramp, below normal storm-wave base down to the basin plain [17]. Inner ramp deposits represent marginal marine deposits indicative of open lagoon and protected lagoon. In the restricted lagoon environment, faunal diversity is low and normal marine fauna are lacking, except for imperforate benthic foraminifera such as miliolids and Dendritina which indicate quite conditions. A large number of porcellaneous imperforates points to somewhat hypersaline waters [30,51]. The presence of imperforate foraminifera that include Archaias, Peneroplis, Dendritina, Meandropsina, Austrotrillina, and miliolids indicates a low-energy, upper photic, shallow lagoonal depositional environment. The large porcelaneous foraminifera types such as Archaias, Peneroplis and Dendritina are present in MF 6. The occurrence of Archaias and Peneroplis is typical of recent tropical and subtropical shallow-water environments [42,34] and are characteristics of the upper part of the upper photic zone (inner ramp). Furthermore, these large porcelaneous foraminifera are also common fossils in the Mesozoic and Cenozoic neritic sediments [14]. And also, inner ramp deposits represent a wider spectrum of marginal marine deposits, indicative of a high-energy reef (MF 3). The middle ramp setting is represented by the medium to fine-grained foraminiferal–bioclastic wacke–packstone dominated by assemblages of larger foraminifera with perforate walls such as Amphistegina, Operculina and Nummulites (Fig. 6). The faunal association suggests that the depositional environment was situated in the mesophotic to oligophotic zone [37,50]. Open lagoon shallow subtidal environments are characterized by microfacies types that include mixed open marine bioclasts (such as red algae, echinoids and corals) and protected environment bioclasts (such as miliolids). The diversity association of skeletal components represents a shallow subtidal environment, with optimal conditions as regards salinity and water circulation. The change in larger foraminiferal fauna from porcelaneous imperforated to hyaline perforated forms point to a decrease in water transparency [9]. The microfacies 1 and 2 are subjected to an open marine environment of a proximal outer ramp and middle ramp, respectively. More common components of the microfacies 1 is biota association, such as large benthic foraminifera (lepidocyclinidae, Nummulites and Operculina), small benthic foraminifera (Neorotalia), coralline red algae which is dominated in lower photic zone. Moreover, the red algae association with these larger foraminifera places the middle ramp in an oligophotic to mesophotic zone [50,37,12,13,14].

Conclusions:

The Oligocene–Miocene Asmari Formation is a thick sequence of shallow water carbonate and is widespread in the Zagros basin. The subsurface section of the Asmari Formation in southeast of the Zagros and Qeshm Island allow the recognition of different depositional environments, on the basis of sedimentological analysis, distribution of foraminifera and microfacies studies. Occurrence of large foraminifera (Nummulites, Operculina, Lepidocyclina, Archaias, Peneroplis), coralline red algae, coral debris and fragments of echinoderms, mollusks and bryozoan represent high nutrient stability in an oligo to mezothrophic and tropical condition existed during deposition of the Asmari Formation. Based on the occurrence of these fossils, two assemblage zones (Eulepidina-Nephrolepidina-Nummulites Assemblage Zone and Miogypsinooids-Archaias-Valvulinid sp. 1 Assemblage Zone) have been recognized and the Asmari carbonate at the study area is Chattian-Aquitanian in age. Based on the occurrence of skeletal (large benthic foraminifera and coralline red algae) and non-skeletal components, the following environmental and paleoecological implications are defined for the Asmari depositional environment at the Qeshm Island, southern Bandar Abbas Hinterland. Based on components and texture, seven microfacies types have been recognized and they are grouped into three depositional environments that correspond to the inner, middle and outer ramp. The microfacies 1 and 2 are subjected to an open marine environment of a proximal outer ramp and middle ramp, respectively. The microfacies 3 to 6 are belong to inner ramp/platform environment. These assemblages of the Asmari Formation suggest that carbonate sedimentation took place in tropical waters and oligotrophic to slightly mesotrophic conditions.

ACKNOWLEDGMENTS

The studies were supported by National Iranian Oil Company (NIOC). The authors wish to thanks the Exploration Directorate (NIOC) for financial support and permission to publish this research.

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