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Biostratigraphy, Paleoecology, Microfacies and Depositional environment of the Asmari formation (Oligocene-Early Miocene) in Karanj oil field, SW Iran

Behzad Saeedi Razavi*

Standard Research Institute, Engineering and Technical Faculty, Construction and Mineral Department, Karaj, Iran

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Abstract

Core data analysis of one well from the Karanj oil field, southwestern Iran, allowed us to precise the biostratigraphy, microfacies and paleoecology of the Asmari Formation. Analysis of thin section from this cored well permitted identification of 28 genera and 20 species of benthic and planktic foraminifera respectively. Subsequently four benthic foraminiferal assemblage biozones were identified, as follows: (1) *Lepidocyclina-Operculina-Ditrupa* Assemblage zone, (2) *Archaias asmaricus-Archaias hensoni-Miogypsinoides complanatus* Assemblage zone, *(3) Miogypsina-Peneroplis farsensis–Elphidium* sp. 14 Assemblage zone and (4) *Borelis melo curdica-Borelis melo melo* Assemblage zone; indicating an Oligocene (Rupelian-Chattian) to early Miocene (Aquitanian to Early Burdigalian) age for the Asmari Formation. Microfacial study of depositional textures led to characterizing 12 microfacies types, indicating environments in five different settings: restricted lagoon, open lagoon, shoal, slope, and basin mostly in the upper Asmari Formation. These sediments had been deposited under 3 different salinity levels (from 34 to more than 50 psu) in an environment ranging from aphotic to oligophotic and to euphotic zones, and under oligotrophic to eutrophic conditions from the Chattian to the Burdigalian on a carbonate platform (homoclinal ramp). In the studied well, the Asmari Formation had been deposited in a marine environment with normal salinity during the Rupelian-Chattian interval and in a marine environment with high salinity during the Aquitanian to the Burdigalian times.

Keywords: *Biostratigraphy, Asmari Formation, Paleoecology, Chattian, Burdigalian.*

1. Introduction

The Asmari Formation, with its impressive thickness of carbonates, in Zagros Basin constitutes one of the largest oil reservoirs in Iran (Alavi 2004). In this section, in the southwestern part of the Asmari Anticline, the Tang-e-Gel Tursh is some 314 metres-thick and consists of medium to thick carbonate beds (Thomas 1950). The thickness of the Asmari Formation varies depending on location area due to the presence of sandstones and anhydrites: from 90 to 594 metres. Accordingly the age of the Asmari Formation also varies. According to general research data, the Asmari Formation in northwestern Iran (Lorestan and Khuzestan) is supposed to be Rupelian to Burdigalian in age whereas, in the southeast Iran (Fars) and the Zagros Basin, it is Rupelian to Chattian (Motiei 1993). Actually recent studies concluded that the Asmari Formation was located on a carbonate unit and its trend is estimated stretching the NW Zagros basin (Sepehr and Cosgrove 2004). Sedimentation on this platform had been moving upward to the shallow area (Fig 1). The Asmari Formation mainly contains marine fauna mostly found in shallow areas. These faunas include benthic foraminifers and corals. (Vaziri-Moghaddam et al. 2006). Many studies had dealt with the stratigraphic and biologic characteristics of the Asmari Formation (James and Wynd 1965; Wynd 1965; Adams and Bourgeois 1967; Ehrenberg et al. 2007; Laursen et al. 2009; van Buchem et al. 2010); however only a small number of these addressed the microbiostratigraphy, microfacies, paleoecology and paleoenvironmental reconstruction of the Asmari Formation (Kakemem et al. 2016). The present study is focused on (1) a description of the respective microfacies and their distribution over the Oligocene-Miocene carbonate platform, (2) the paleoenvironmental reconstruction of the carbonate platform based on the benthic foraminiferal assemblages and (3) the paleoecological aspects of the Asmari Formation.

2. Geological setting and location of studied section

The Zagros Mountain range, some 2,000 km-long and 300 km-wide, extends beyond southeastern Turkey-Armenia, continues with a NE-SW trend to the Strait of Hormuz, and is located in the southernmost part of the central plateau of Iran. This topographic position represents an orogenic belt (Alpine belt), its deformation of started by the late Cretaceous with the drifting of the Arabic continental plate to the continental plate of Iran, and culminated in the Miocene. The orogenic belt of Zagros is confined from the northwest to dextral strike–slip fault in the east of Anatolia, and from the south-east to the transform and dextral fault of Minab-Oman (Falcon 1974; Alavi 2004; Saeedi Razavi & Keshavarz 2021). Nowadays oil geologists structurally and geo-morphologically divide the Zagros from southwest to northeast into three sub-areas, including a lower folded zone (Abadan plain), a simply folded belt (outer Zagros) and a high Zagros belt(inner Zagros) (Fig 2).

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*Corresponding author.
E-mail address (es): bsaidi@standard.ac.ir

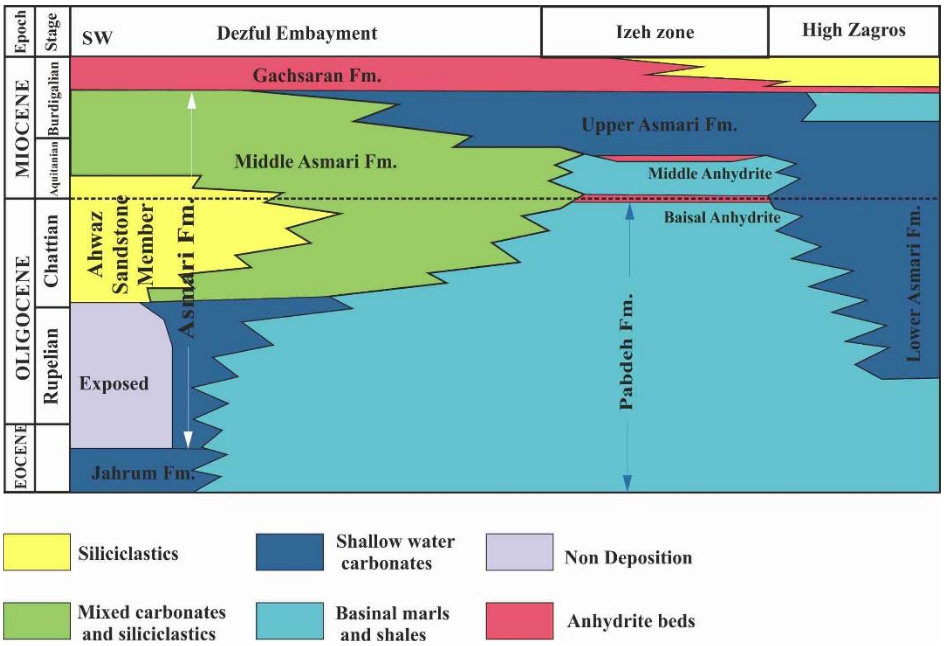

Fig 1. Correlation chart along a SW-NE profile in the Zagros basin (modified from van Buchem et al. 2010)

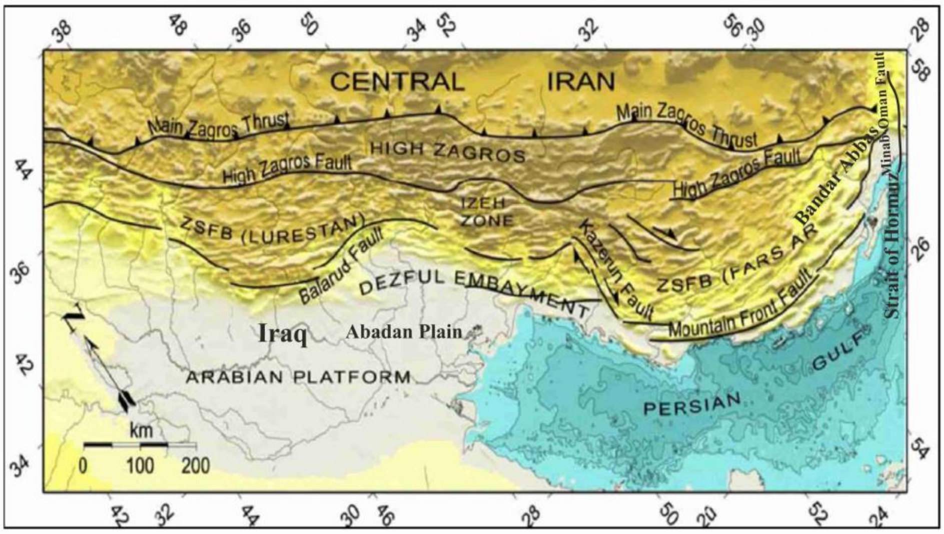

Fig 2. Classification of structural domains of the Zagros area.

One of the most important parts of the Zagros zone is the folded Zagros. The Karanj oil field is located in this area. Structurally, this zone, mostly trending from northwest to southeast, is a trench in the continental margin of the northeastern Arabian plate (approximate width: 150 to 250 km) and exposes a thick sequence of continental shelf deposits, dating from the late Precambrian to Pliocene, and its younger sediments. During the Paleozoic and Mesozoic periods, this zone had been continuously subsiding and deposited marine sediments; now it is the site of oil traps and cap rocks related to northeastern Iraq and southwestern Iran. Moreover this zone also presents some other subsiding areas such as the Lurestan Basin, Izeh Zone, Dezful embayment, Fars Basin, and the Bandar Abbas. From a petroleum geological point of view, the Dezful embayment is very important because it contains most oil reserves and delivers the major oil production in Iran (the Karanj oil field inclusive). This area located in the folded Zagros, is part of the Zagros pit; here the Asmari Formation shows no visible porosity. This subsiding region is limited by three structural features. These are, arranged in a winded line running from the north to the southeast, (1) the west-east running Balarud fault, (2) the north-south running

Qatar-Kazerun fault, and (3) the west-east running Mountain front fault (Fig 2). The Karanj anticline structure is one of the most important productive oil fields in Iran and is located in the southwestern Zagros basin and in the southernmost part of the northern Dezful embayment (Fig 3, 4) (Sherkati and Letouzey 2004; Baratian et al. 2020), in the vicinity of the Parsi and Perenj fields. The study well section is located 115 km east of Ahwaz at geographical coordinates N31°04 48", E49°58'13".

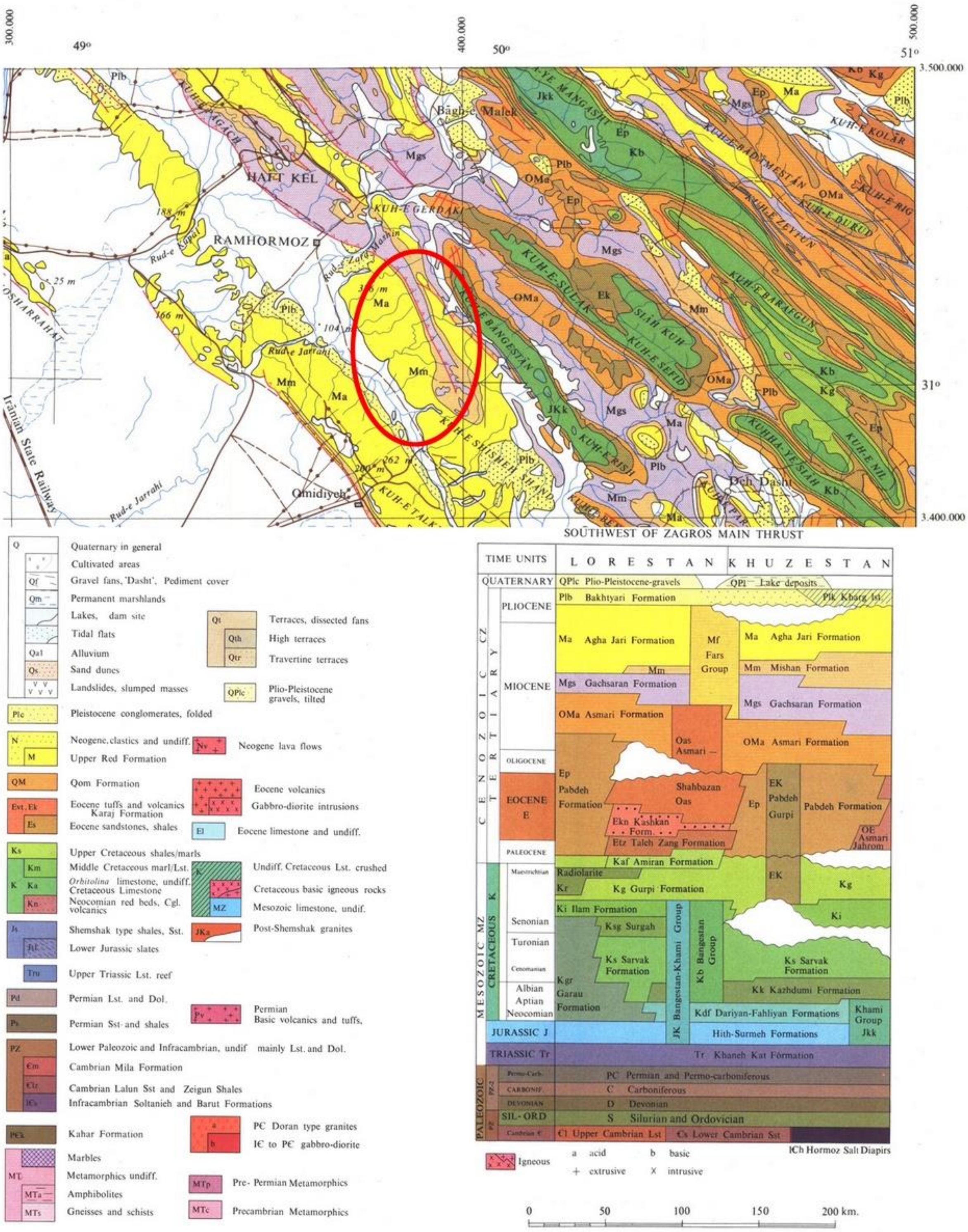

Fig 3. Location of the Karanj oil field in the geological map (National Iranian Oil Company)

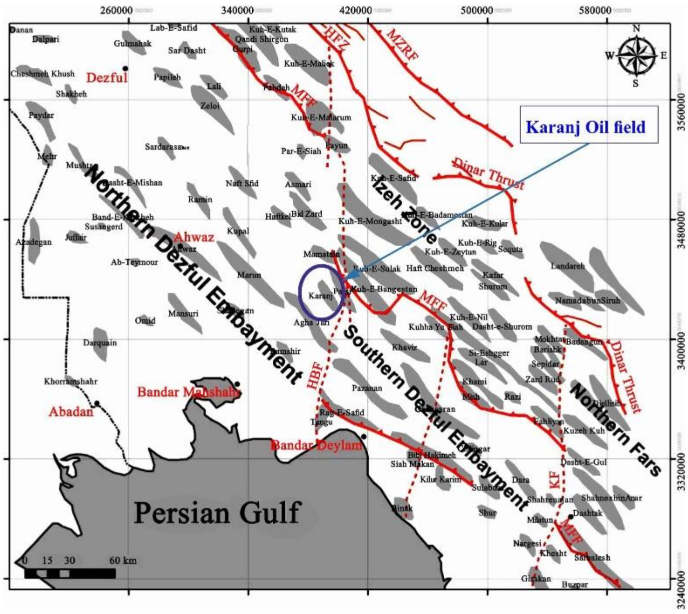

Fig 4. Location of the Karanj oil field within the Zagros area (adapted from Sherkati and Letouzey 2004).

3. Material and methods

145 selected samples from the Asmari Formation were analyzed; they were generally taken at intervals of 1 to 2 metres. In the laboratory, about 154 thin sections were prepared for optical microscopy analysis. The first stage aims to precise the biostratigraphy of the Asmari Formation based on benthic and planktic foraminifers (Laursen et al. 2009; Jafari and Yazdi 2014). Meanwhile the carbonate microfacies were identified according the classification of Dunham (1962) and Embry and Klovan (1971). Paleoenvironmental reconstruction and paleoecological interpretations such as temperature, salinity, light, nutrients, depth, hydrodynamics, and substrate, are based on extensive studies (Wilson 1975; Read 1985; Burchette and Wright 1992; Langer and Hottinger 2000; Geel 2000; Romero et al. 2002; Hohenegger 2000, 2004; Wilson and Vecsei 2005; Mossadegh et al. 2009; Brandano et al. 2009, 2010; Flügel 2010; Ghaffari et al. 2015; Yazdi et al. 2019).

4. Microbiostratigraphy

The planktic and benthic foraminiferal assemblages, including a total number of 28 genera and 20 species, were analyzed to establish the biostratigraphic framework (Oligocene to Miocene) of the Asmari Formation in the studied section. From base to top, four Assemblage Zones were then recognized (Fig 5 and 6).

***Lepidocyclina-Operculina-Ditrupa* Assemblage zone**

This biozone is located in the lower part of the Asmari Formation in the studied well, is 40 metres-thick (Depth: 2730m-2770m) and contains the following microfossils: *Eulepidina dilatata*, *Eulepidina elephantina*, *Ditrupa* sp., *Eulepidina* sp., *Nephrolepidina tournoueri*, *Nephrolepidina* sp., *Lepidocyclina* sp., *Heterostegina* sp., *Operculina complanata*, *Operculina* sp., *Neorotalia viennoti*, *Neorotalia* sp., *Elphidium* sp., *Globigerina* sp., *Globorotalia* sp. valvulinid sp., *Haplophragmium* sp., *Lenticulina* sp., *Planorbulina* sp., textulariids, *Amphistegina* sp., *Discorbis* sp., *Onychocella* sp., *Pyrgo* sp., and *Triloculina* sp.

This assemblage corresponds to the *Lepidocyclina-Operculina-Ditrupa* Assemblage Zone of Laursen et al. (2009) and van Buchem et al. (2010), and contains index fossils such as *Eulpidina dilitata* (early Rupelian to Chattian) and *Nephrolepidina tournoueri* (middle Rupelian to early Aquitanian) (van Buchem et al., 2010). According to Ehrenberg et al. (2007), this assemblage characterizes the Chattian basin, due to the absence of *Nummulites* sp. and its assignement to fauna 3 (Adams and Bourgeois 1967). Table 1 did not introduce an independent biozone for such an assemblage. Consequently the considered age range for this assemblage is Rupelian- Chattian (Kakemem et al. 2016).

***Archaias asmaricus-Archaias hensoni-Miogypsinoides complanatus* Assemblage zone**

This biozone is located in the middle part of the Asmari Formation, is 53 metres-thick (Depth: 2770m-2823m) and contains the following microfossils: *Archaias kirkukensis*, *Archaias hensoni*, *Archaias asmaricus*, *Peneroplis thomasi*, *Austrotrillina asmariensis*, *Peneroplis evolutus*, *Triloculina tricarinata*, *Dendritina rangi*, *Miogypsinoides complanatus*, *Triloculina trigonula Miogypsina* sp., *Elphidium* sp., *Discorbis* sp., *Heterostegina* sp., textulariids and miliolids.

The benthic foraminifers are of Chattian age and they are time equivalent to the *Archaias asmaricus-Archaias hensoni-Miogypsinoides complanatus* Assemblage Zone of Laursen et al. (2009). The absence of *Austrotrillina howchini* supports their actual age as Chattian (Cahuzac and Poignant 1997; Kakemem et al. 2016).

Fig 5. Thin sections showing foraminifera: 1) *Neorotalia viennoti*, Greig 1935, 2) *Amphistegina* sp., 3) *Operculina complanata*, Defrance 1822, 4) *Nephrolepidina tournoueri*, Lemoine and Douville 1904, 5) *Heterostegina* sp., 6) Serpulid *Ditrupa* sp., 7) *Austrotrilina howchini*, Schlumberger, 1893, 8) *Austrotrillina asmariensis*, Schlumberger, 1893, 9) *Borelis melo curdica* (Reichel) 1937, 10) *Asterigerina* sp., 11) *Elphidium* sp., 12) *Pyrgo* sp., 13) *Triloculina tricarinata* d, Orbigny 1826,, 14) *Miogypsinoides complanatus*, Henson 1950, 15) *Meandropsina iranica*, Henson 1950, 16) *Meandropsina anahensis*, Henson 1950, 17) *Peneroplis evolutus*, Henson 1950, 18) *Miogypsinoides complanatus*, Henson 1950, 19) *Eulepidina elephantine*, Lemoine and Douville 1904, 20) *Eulepidina dilatata*, Lemoine and Douville 1904, 21) *Peneroplis thomasi*, Henson 1950, 22) Valvulinidae, *23) Dendritina rangi*, d, Orbigny Fornasini 1904, 24) *Globigerina* sp., 25) *Meandropsina iranica*, Henson 1950, 26) *Archaias hensoni*, Adames 1967, 27) *Archaias kirkukensis*, Henson 1950, 28) *Peneroplis farsensis*, Henson 1950, 29) *Elphidium* sp. 14, 30) Serpulid *Ditrupa*, 31) *Globigerina* sp., 32) *Borelis pygmaea*, Hanzawa 1930.

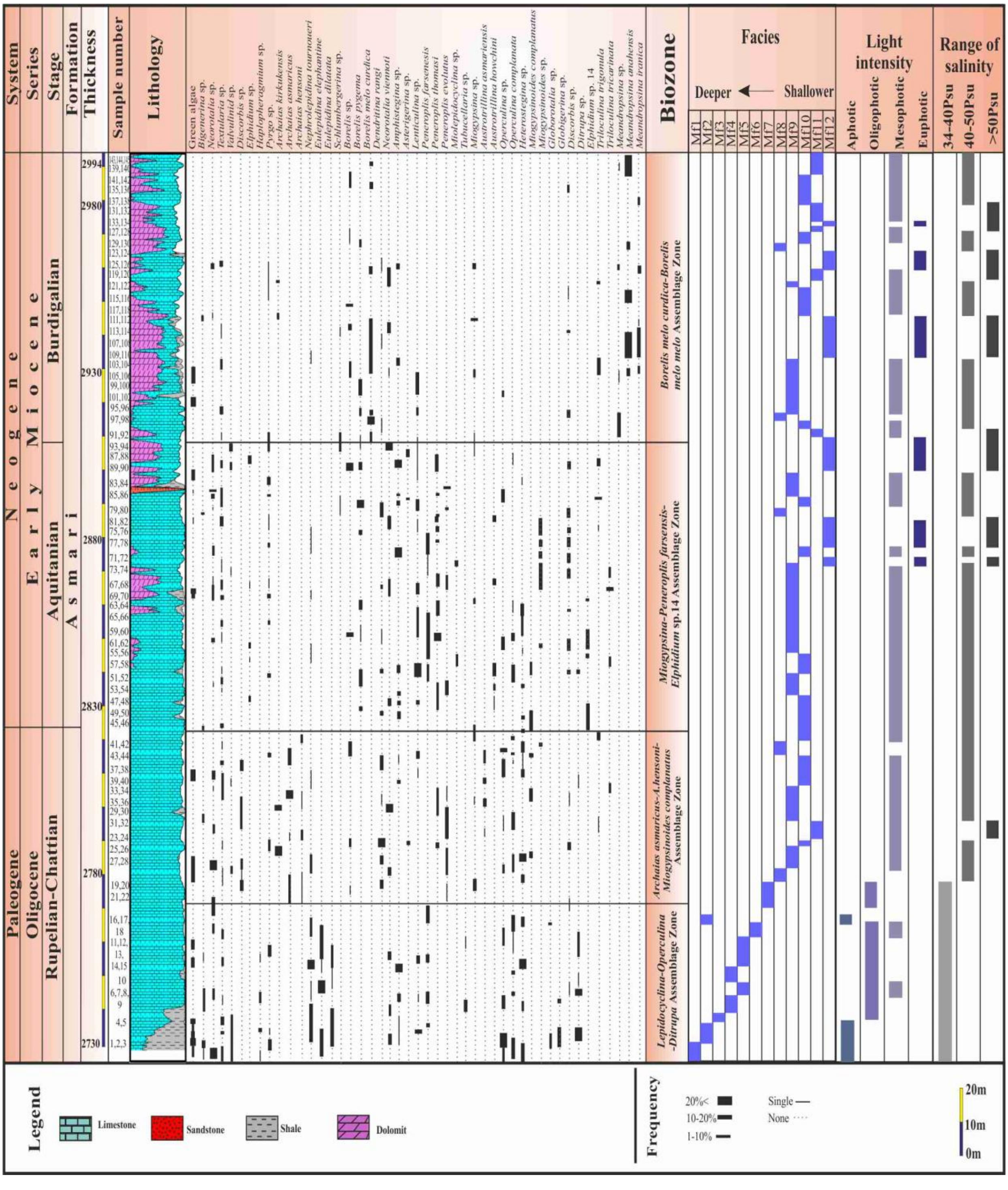

Fig 6. Biostratigraphy of the Asmari Formation, stratigraphical ranges of foraminifera, other biota and process of changes in salinity and light in the studied section

***Miogypsina-Peneroplis farsensis–Elphidium* sp. 14 Assemblage zone**

This biozone is located in the middle part of the Asmari Formation, is 85 metres-thick (Depth: 2823m-2908m) and contains the following microfossils: *Elphidium* sp. 14, *Miogypsina* sp., *Operculina complanata*, *Lepidocyclina* sp., *Austrotrillina asmariensis*, *Austrotrillina* sp., *Austrotrillina howchini*, *Peneroplis thomasi*, *Peneroplis* sp., *Peneroplis farsensis*, *Triloculina trigonula*, *Peneroplis evolutus*, *Miogypsinoides* sp., *Meandropsina iranica*, *Borelis* sp., *Meandropsina anahensis*, *Archaias asmaricus*, *Dendritina rangi*, *Archaias hensoni* , *Neorotalia viennoti*, *Heterostegina* sp., *Archaias* sp., *Amphistegina* sp., *Pyrgo* sp., *Asterigerina* sp., *Discorbis* sp., miliolids, valvulinids. This assemblage corresponds to the *Miogypsina*–*Elphidium* sp. 14-*Peneroplis farsensis* Assemblage Zone of Laursen et al. (2009) and van Buchem et al. (2010). The presence of index fossils such as *Peneroplis farsensis*, *Elphidium* sp.14 and *Miogypsina* sp., the absence of *Archaias* sp., (*Archaias* sp., disappeared in the Chattian) and *Borelis melo curdica* (Burdigalian index) all support an Aquitanian age for this assemblage zone (Vaziri-Moghaddam et al. 2006; Mahdavi et al. 2015 Kakemem et al. 2016).

Tab. 1. Comparision of the Asmari Formation biozones of Wynd (1965), Adams and Bourgeois (1967), Cahuzac and Poignant (1997), Laursen et al. (2009) and Roozpeykar and Iraj Maghfouri Moghaddam 2016)

Stage		Wynd(1965)	Adams and Bourgeois (1967)	Cahuzac and Poignant (1997)	Laursen et al., 2009	Roozpeykar and Maghfouri -Moghaddam., 2016
Burdigalian		*Borelis melo curdica* (zone 61)	*Borelis melo group-Meandropsina iranica*	*Borelis melo group-Miogypsina*	*Borelis melo curdica-Borelis melo melo*	*Borelis melo curdica-Borelis melo melo*
Aquitanian		*Austrotrillina howchini Peneroplis evolutus* (zone 59)	*Elphidium* sp.14 *-Miogypsina*; *Archaias asmaricus-Archaias hensoni*; *Miogypsinoides-Archaias-Valvulinid*	*Austrotrillina howchini-Miogypsina-Miogypsinoides deharti*	Indeterminate zone; *Miogypsina-Peneroplis farsenesis -Elphidium* sp.14	*Miogypsina-Peneroplis farsenesis -Elphidium* sp.14
Oligocene	Chattian	*Archaias operculinoformis* (zone 58); *Nummulites intermedius-Nummulites vascus* (zone 57)	*Eulepidina-Nephrolepidina-Nummulites*	*Miogypsinoides-Eulepidina*; *Nummulites vascus-Nummulites fichteli-Eulepidina*	*Archaias asmaricus-Archaias hensoni-Miogypsinoides complanatus*	*Lepidocyclina-Operculina -Ditrupa*
	Rupelian	*Lepidocyclina-Operculina-Ditrupa* (zone 56); *Globigerina spp.* (zone 55)		*Eulepidina formosoides*; *Nummulites vascus-Nummulites fichteli*	*Nummulites vascus -Nummulites fichteli*; *Lepidocyclina-Operculina -Ditrupa*; *Globigerina-Turborotalia-Hantkenina*	

***Borelis melo curdica-Borelis melo melo* Assemblage zone**

This biozone is located in the upper part of the Asmari Formation, is 86 metres-thick (Depth: 2908m-2994m) and contains the following microfossils: *Dendritina rangi*, *Borelis melo curdica*, *Meandropsina anahensis*, *Meandropsina iranica*, *Amphistegina* sp., *Triloculina tricarinata*, *Discorbis* sp., *Borelis* sp., textulariids ang miliolids.

This assemblage zone corresponds to the *Borelis melo curdica-Borelis melo melo* Assemblage Zone of Laursen et al. (2009) and van Buchem et al. (2010). Due to the presence of *Borelis melo curdica*, this assemblage zone can be assigned to the early Miocene (Burdigalian) (Kakemem et al. 2016).

5. Facies types and depositional environments

From the study of 103 thin sections, 12 facies types were recognized in the Asmari Formation (Tab 2). These facies types (MF1-MF12) were classified according to their respective sedimentary texture and assemblage of foraminifers and other skeletal elements (Dunham 1962; Embry and Klovan 1971; Wilson 1975; Flügel 2010).

6. Depositional model and sediment distribution

Identified microfacies characterized a variety of carbonate marine environments: restricted lagoon, open lagoon, shoal, slope, and basin. These five sedimentary environments ranging from the Oligocene to the Miocene, are very similar to recent carbonate depositional settings (Read 1985; Jones and Desrochers 1992). The Persian Gulf is such an example for deep water setting, very similar to the Zagros basin. According to regional studies on the study area, sedimentology and paleontology both indicate that the regional sedimentary model was a carbonate platform structure (Read 1982; Tucker 1985; Tucker and Wright 1990). According to Burchette and Wright (1992), the texture of the outer shelves is rich in planktic foraminifers (*Globigerina* and *Globorotalia*). Factors such as the presence of granular tissue and the absence of waveform structures indicate that water energy is low (Burchette and Wright 1992). In the Asmari Formation, large perforated foraminifers are the most commonly used components in the shallow water deposits of the region. Presence of perforated foraminifers and their expansion in region indicate normal marine conditions (Geel 2000). The lack of abrasion of foraminifers indicates autochthonous assemblages; thus wackestone-packstone textures with lepidocyclinids and nummulitids were deposited under low energy conditions, below fair weather wave base (FWWB) and above storm wave base (SWB) in a middle ramp setting. Successive samples illustrate difference in water depth in different areas. Sediments contain oval-shaped elliptical specimens of lepidocyclinids and nummulitids; their presence in the region indicates shallow waters. Large foraminifers occur in tropical to sub-tropical regions (Hohenegger et al. 2000; Langer and Hottinger 2000). The presence of symbiotic algae and vermicular foraminifers indicate that light is the main factor in water depth estimation (Hallock 1981, 1988; Hallock and Glenn 1986). Inner shelf sediments over a vast marine sediment area indicate high flood and energy shoal, open lagoon and protected lagoon. In a slender and restricted environment, size and diversity of marine organisms are quite low, except foraminifers, occurrence of which documents a quiet environment. Occurrence and distribution of imperforated foraminifers in the region both indicate a very low water salinity (Geel 2000). Open lagoonal conditions are characterized by mixed open-marine fauna (such as red algae, echinoids and perforate foraminifers) and protected environment fauna (such as miliolids). The shallow subtidal environment above FWWB is represented by a high energy environment indicating that waters of this area were highly agitated and oxygenated. Such sediments are usually accumulated in a carbonate system (Fig 7).

7. Paleoecology

Perforated foraminifers are one of the most important paleontological resources in Cenozoic carbonate platforms: a subtle relation exists between fossil genera fossils and their morphological types due to factors such as depth, light, and bedrock characteristics that all interfere with fossil morphologies preserved in carbonate sections. For this reason, perforated foraminifers are considered suitable for the reconstruction of environment (Romero et al. 2002). In this paper, we addressed the factors affecting the formation of carbonate grains, especially large foraminifers, which constitute the most important fossil group in the Asmari Formation. Therefore they provide baseline data to the reconstruction of paleo-environment and environmental changes (Fig 6).

7.1. Salinity

Based on internal reports (Rasser et al. 2005; Logan 1959), salinity of the study area was subdivided into 3 zones from their psu (Fig 8).

7.1.1. Psu salinity 34-40

This range indicates normal salinity for sea water, characterized by the presence of hyaline foraminifers. This normal salinity range is documented by MF1 to MF5 microfacies with high foraminiferal diversity such as *Lepidocyclina spp.*, *Nummulitidae*, *Amphistegina* spp. and Neorotalia spp., and corallinaceans, echinoid and bryozoan fragments. Amount of imperforate foraminifers inferior to 30% of the total assemblage, will also be reported to this salinity range. Accordingly, considering that less than 30% of foraminifers are imperforated species and from the large presence of hyaline foraminifers, microfacies MF6 and MF7 should also be reported within this normal salinity range. Along the study well, normal salinity occurred during the Rupelian-Chattian times (Fig 6).

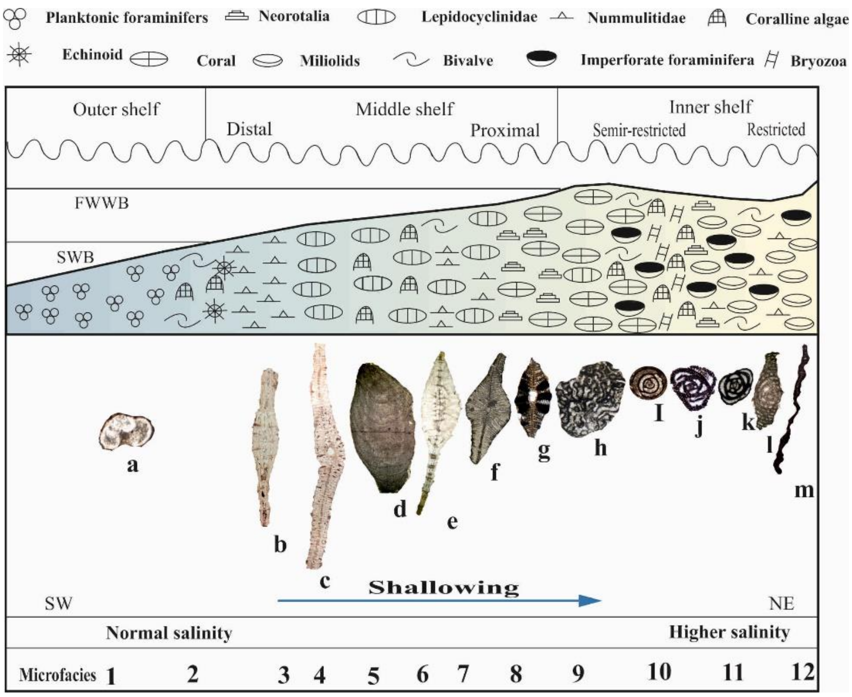

Fig 7. Sedimentation and dispersion model of foraminifers, corals and corallinaceans within carbonate shelves in the Asmari Formation, based on depth, light intensity and water energy of studied environments: a- Planktic foraminifera, b- *Operculina complanata,* c- *Eulepidina elephantine,* d- corallinacean, e- *Heterostegina* sp., f - *Lepidocyclina* sp., g- *Nephrolepidina tournoueri;* h- corals*;* i- *Pyrgo* sp.*;* j- *Austrotrillina* sp.*,* k- miliolids, l- *Archaias* sp., m- *Meandropsina* sp. (adapted from Flügel 2010).

Tab. 2. Description of respective sedimentary facies and their environmental significance in the study area

Facies		Facies Descriptions	Environment	
MF1	Planktic foraminiferal wackestone	Fine grained and muddy material with mud-supported texture. Main elements planktic foraminifera (*Globigerina* spp. and *Globorotalia* spp.).	Lower offshore (below SWB)	Outer shelf
MF2	Planktic foraminiferal-echinoid packstone	Grain-supported packstone texture. Main elements echinoids and planktic foraminifers. Minor elements: Miliolids (*Pyrgo* spp and *Triloculina*), bryozoans, *Ditrupa* spp., crushed corallinaceans, *Neorotalia* spp. and textulariids.	Upper offshore (under storm conditions)	Outer shelf
MF3	Bioclastic *Operculina* packstone	Grain-supported texture. Major skeletal component: *Operculina* spp., a larger symbiont-bearing foraminifer. The hyaline tests of *Operculina* are either long and thin and well-preserved, or thick and crushed. Crushed *Operculina* tests are fractured and eroded. Secondary skeletal components: echinoid debris, corallinaceans, bryozoans, *Ditrupa*, *Neorotalia*, *Lepidocyclina*, *Heterostegina*, planktic foraminifers, and textulariids. Crushed tests of miliolids and unbroken textulariid tests also occur.	Upper offshore (Below FWWB)	Middle shelf
MF4	Bioclastic Lepidocyclinidae packstone–rudstone	Basic elements: hyaline elongated tests (>2 mm) of Lepidocyclinidae (*Nephrolepidina* and *Eulepidina*). Minor skeletal components: *Amphistegina*, *Neorotalia*, bryozoans, echinoids, corallinacean fragments, and oyster debris	Upper offshore (Below FWWB)	Middle shelf
MF5	Bioclastic corallinacea Lepidocyclinidae packstone-rudstone	Main constituents: corallinaceans and Lepidocyclinidae (*Nephrolepidina*). Minor associated elements: *Neorotalia*, *Amphistegina*, textulariids, echinoid debris, *Ditrupa*, and peloids. Some miliolinas, such as *Pyrgo*, *Borelis* and miliolids, also occur.	Upper offshore (Below FWWB)	Middle shelf
MF6	Lepidocyclinidae-Nummulitidae wackestone–packstone–grainstone	Major elements: hyaline foraminifers (Lepidocyclinidae and Nummulitidae) and corallinaceans, Minor components: *Amphistegina* spp., *Neorotalia* spp., echinoids, oyster debris, and coral fragments. Size decrease of Lepidocyclinidae and Nummulitidae tests but with thicker walls.	Upper offshore (Below FWWB)	Middle shelf
MF7	Bioclastic Lepidocyclinidae *Neorotalia* packstone–rudstone	Major constituents: *Neorotalia* and Lepidocyclinidae. Minor elements: corallinaceans, small-sized hyaline foraminifers with *Amphistegina*, valvulinids, echinoids, bryozoans, and crushed flakes of large hyaline foraminifers (Lepidocyclinidae, *Operculina*, and *Heterostegina*).	Upper offshore (Below FWWB)	Middle shelf
MF8	Coral boundstone	This coral boundstone is mainly built by massive and branching coral colonies all in growth position.	Upper offshore (shoal)	Middle shelf
MF9	Bioclastic miliolid-coral packstone-rudstone	Main components: coral fragments and diverse porcellaneous foraminifers (miliolids, *Meandropsina*, *Peneroplis*, *Archaias*, *Austrotrillina*, and *Pyrgo*). Secondary skeletal components: *Amphistegina* and *Neorotalia*,. Minor components: Gastropods, corallinacean algae, echinoids and bryozoan debris. Corals in this facies were observed only as crushed fragments.	Upper offshore (open lagoon)	Inner shelf
MF10	Bioclastic corallinacean-bryozoan wackestone–packstone	Main components: bryozoans and corallinaceans. Secondary constituents: bivalves, echinoids, small individuals of *Neorotalia*, debris of Lepidocyclinidae and porcellaneous foraminifers (*Archaias* and *Peneroplis*).	Upper offshore (open lagoon)	Inner shelf
MF11	Bioclastic benthic foraminiferal (perforate and imperforate) wackestone–packstone	Main components: bryozoans and corallinaceans. Secondary constituents: bivalves, echinoids, small individuals of *Neorotalia*, debris of porcellaneous foraminifers (*Archaias* and *Peneroplis*).	Upper offshore (open lagoon)	Inner shelf
MF12	Bioclastic benthic foraminifera (imperforate) wackestone–packstone	Mud- to grain-supported texture. Main constituents: porcellaneous foraminifers: *Archaias*, *Peneroplis*, *Austrotrillina*, *Pyrgo*, *Borelis* and *Meandropsina*. Minor components: small specimens of gastropods and bivalve debris. Most porcellaneous foraminifers with thinner wall.	Upper offshore (restricted lagoon)	Inner shelf

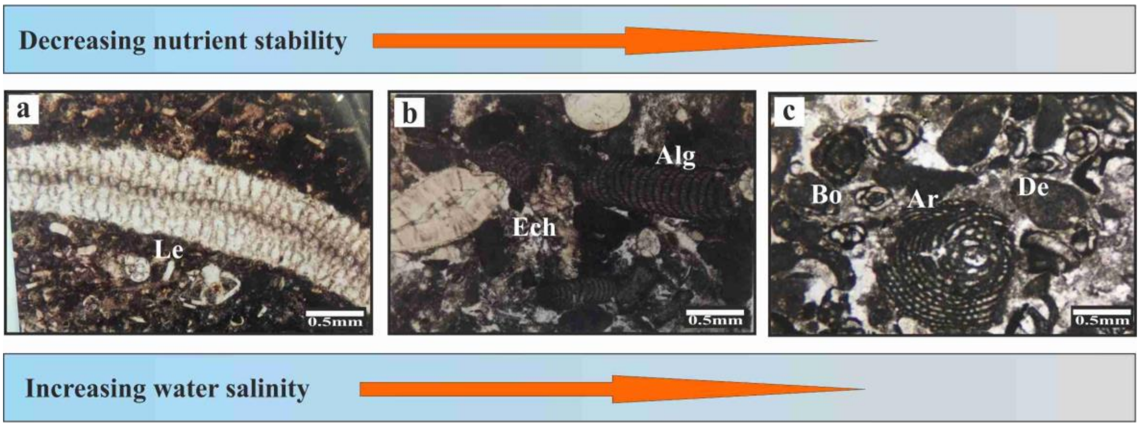

Fig 8. These forms illustrate the imperforated red algae requiring high salinity water and also show their mutual relationship (Le: *Lepidocyclina*, Alg: Algae, Ech: Echinoid, Bo: Borelis, Ar: Archaias, De: Dendritina).

7.1.2. Psu salinity 40-50

Presence of imperforated foraminifers, agglutinant foraminifers or echinoid fragments, and increased diversity of biogenic grains all characterize this salinity range. In such a range, hyaline foraminifers are also available, but with lower diversity. This range represents high salinity in lagoon (Baratollo et al. 2007). Accordingly, we can conclude that microfacies MF9 and MF10 is reported to such a salinity range. Recent studies in the Asmari Formation showed that its upper and middle parts mostly display a salinity of 40-50 psu. This salinity had taken place during the Chattian, Aquitanian and Burdigalian times (Fig 6).

7.1.3. Psu salinity >50 (hypersalinity)

Organisms from that salinity range include molluscan fragments and imperforate foraminifers making up more than 80% of the total foraminifer assemblage. This salinity range is characteristic of a lagoon.Within this salinity also miliolids occur (Mossadegh et al. 2009). According to these interpretations, microfacies MF11 falls within this range due to the presence of imperforated foraminifers such as miliolids and dendrites, and the absence of echinoids and open marine faunas. Microfacies MF12 and the absence of open marine fossil faunas indicate a lack of favorable conditions. This salinity had occurred during the Aquitanian and Burdigalian (Fig 6).

7.2. Nutrient

One of the effective factors in the foraminiferal distribution is nutrient availability that plays an important role in the carbonate production (Flügel 2004). Nutrient dispersal for benthic foraminifera is a very important factor in shallow waters and tropical areas. Algae, as phototrophic and mesotrophic organisms, co-occur in the carbonate factory (Pomar 2001; Wilson and Vecsei 2005). Accordingly, marine environments can be divided into 4 groups: 1- oligotrophic (low nutrient), 2- mesotrophic (medium nutrient), 3- eutrophic (high nutrients) and 4- hypertrophic (maximum nutrients) (Mutti and Hallock 2003). The carbonate platform sediments of the Asmari Formation (study area) originated from the expansion and dispersal of biotas and nutrients under different conditions. Oligotrophic to low mesotrophic nutrition condition in shallow waters of the tropical to sub-tropical environments, large benthic foraminifers and red algae are the main carbonate producers (Pomar et al. 2004; Brandano et al. 2009). Therefore, from the co-occurrence of large benthic foraminifers, coral and red algae in the lower part (Chattian age) of the Asmari Formation, they were mainly present in such nutrition conditions. The nutrient increase into eutrophy led to phytoplankton blooms. Under these conditions, miliolid and rotaliid foraminifers were replaced by large foraminifers (Beavington-Penney and Racey 2004). In this condition, the growth of coral and light-dependent organisms decreased; therefore shallow-water species are replaced with lower diversity (Hallock 2001) (Fig 7). Therefore, in the upper part of Asmari Formation, the decrease in number of large foraminifers was due to nutrient reduction in this area during the Aquitanian and Burdigalian times; meanwhile we also notice the increase of organisms not-dependent on light. These include: echinoids, bryozoans and bivalves, that all live under weak mesotrophic and eutrophic nutrition conditions.

7.3. Light

The carbonate production under any conditions (directly and indirectly) depends on the light in the water column. Light intensity in the seas is controlled by both the transparency and depth of water, because the depth of the water decreases the intensity of the light and increases its transparency (Hallock 1988). Based on the presence of organisms, the photic zones in marine waters are divided into a euphotic zone (high light), a mesophotic (medium light), an oligophotic (low light), and an aphotic (without any light) (Pomar 2001). The three identified photic zones in the study core section are:

7.3.1. Aphotic zone

This zone includes a deep area without any light. Organisms dwelling this area do not depend on light (Flügel 2004); they are heterotrophic, so that they can adapt themselves to any environment (need for bed, temperature, salinity or hydraulic energy). Bryozoans, molluscs, echinoids, brachiopods, and sponges make up most of these in this zone. Different groups of foraminifers are compatible with this light domain. Water turbulence, density of plankton and input of clastic materials naturally reduce the transparency of water. As a result, light travels less deep. When the depth of water increases, the intensity of light shrinks, making the species that match their low light to roam in greater depth. However, in this case, most of them are wiped out (Hallock et al. 1986). Microfacies MF1 and MF2 both document this zone. Accordingly, the lower part of the study well section was formed during the late part of the Rupelian to Chattian times under aphotic condition (Fig 6).

7.3.2. Oligophotic zone

Organisms dwelling in this low light penetration zone, all live in shallow or deeper sections of the continental shelf. Red algae and a number of large foraminifers live in such light conditions (Pomar 2001). Large benthic foraminifers live in an environment where light levels are very low, their morphology adapts to maximizing light absorption and their tests widening and thinning (Rasser et al. 2005). This light range corresponds to the lower photic zone as defined by Bassi et al. (2007). Accordingly, microfacies MF3, MF4 that includes large Lepidocyclinas and Nummulitidae with expanded tests, and red algae, falls within this range (Fig 6).

7.3.3. Mesophotic zone

This zone is intercalated between the oligophotic and euophotic zones, and is considered a subzone (Hottinger 1997). Biota living in this in-between zone include foraminifers with hyaline walls and swollen tests (Pomar 2001). This range belongs to the lower parts where imperforated foraminifers are found, as suggested by Bassi et al. Accordingly, microfacies MF5, MF6 and MF7 that both contain corallinacean fragments and benthic foraminifers with lens-shaped test, fall within the oligophotic to mesophotic zones (Pomar 2001). It should also be noted that microfacies MF9, MF10 and MF11 containing perforated tests and imperforated foraminifers such as miliolids, is located in the mesophotic zone. Therefore sedimentation of the lower part of the Asmari Formation had taken place under oligophotic, oligophotic to mesophotic and, at lesser extent, mesophotic conditions during the Chattian, Aquitanian and Burdigalian (Fig 6).

7.3.4. Euphotic zone

This zone is characterized by shallow waters and high-light. Organisms dwelling this zone require light for living. This zone consists of two subzones: the lower and upper euphotic subzones (Flügel 2004). In the lower euphotic subzone, coral fragments with imperforated foraminifers are visible (Schuster and Wielandt 1999). In the upper euphotic subzone, there are large perforated foraminifers, dinophyceans, cholorophyceans, and rhodophyceans (Leutenegger 1984; Romero et al. 2002). This zone is equivalent to the upper photic zone of Bassi et al. (2007). Presence of a large number of imperforated foraminifers represents the upper euphotic zone. Microfacies MF12 represents this zone. Accordingly, the middle and upper parts of the study well section were formed during the Aquitanian and Burdigalian times under euphotic conditions.

7.4. Water depth

Reconstructing water depth to precise sedimentary model and water surface to identify its characteristics is cardinal (Perrin et al. 1995). According to water depth, foraminifers display specific morphological characteristics, so any change in water depth and sea level is mirrored in their eco-morphological types (Brandano et al. 2009). The depth of large light-dependent foraminifers depends on environmental hydrodynamics (waves and sea currents) (Hottinger 1983). The degree of dependence on light of symbiotic algae constrains its depth range for thriving. There is a correlation between the depth of foraminiferal habitat and its coexistence type. Species with symbiotic algae such as cholorophyceans, live at depth of about 15 metres, such as Peneroplis spp. and some species of Archaias. Species with symbiotic diatoms can be found in deeper waters but less than 130 metres, such as Lepidocyclina spp., Nummulitidae, Amphistegina spp. (Leutenegger 1984). Changing depth of habitat for different species implies changing their morphological characteristics: for example hyaline foraminifers with thicker test occur in shallow zone (Fig 8). The reduction of photosynthesis in algae is also a factor contributing to the formation of thicker shells in adverse light conditions (higher light vs. lower light). At greater depths, the surface of the foraminiferal test is definitely opaque, large and flat, and subsequently the thinnest. In such condition, the foraminifers increase their surface area to maximize their light absorbance (Beavington-Penney and Racey 2004). Imperforated foraminifers living in the shallowest lagoon segments with high salinity lack symbiotic algae (Mossadegh et al. 2009). But complex non-porous foraminifers with symbiotic algae, such as Archaias spp., cannot tolerate high salinity at lower depth and live in greater depth than the miliolids (Lee 1990). The position of some foraminifers in the carbonate platform of the Asmari Formation is shown in Figure 9.

7.5. Temperature

Temperature is the most important issue for the formation of benthic foraminiferal tests and carbonate producers (Flügel 2004). Water temperature varies according to water depth (Hottinger 1997). The presence of large benthic foraminifers represents tropical and semi-tropical climates showing a temperature of 18-20$^{\circ C}$. In tropical and semi-tropical climates, large benthic foraminifers live at temperatures of 18-20°C in the warm months of the year. However many of them live at 25°C in the summer (Adams et al. 1990). Red algae are also tropical climate indicators, so they are carbonate producers (Pomar et al. 2004). Corals also prefer living in warm waters with a temperature of 23-24˚C (Brandano et al. 2009). In the study area, with respect to the abundance of large benthic foraminifers such as species of the genera Lepidocyclina, Operculina, Heterostegina, Miogypsinoides, Amphistegina, Archaias, Borelis, etc., as the main components of the carbonate deposit formation, the presence of red algae, corallinaceans, fragments of coral, and the presence of non-skeletal elements such as ooids, all indicate warm waters and tropical and sub-tropical environments (Flügel 2004). We can then easily conclude that sedimentation of the Asmari Formation in the study area had occurred in a tropical to sub-tropical environment, and that the Zagros Mountains were located during the Oligocene-Miocene times at 29˚ latitude north (tropical) (Heydari 2003) (Fig 10).

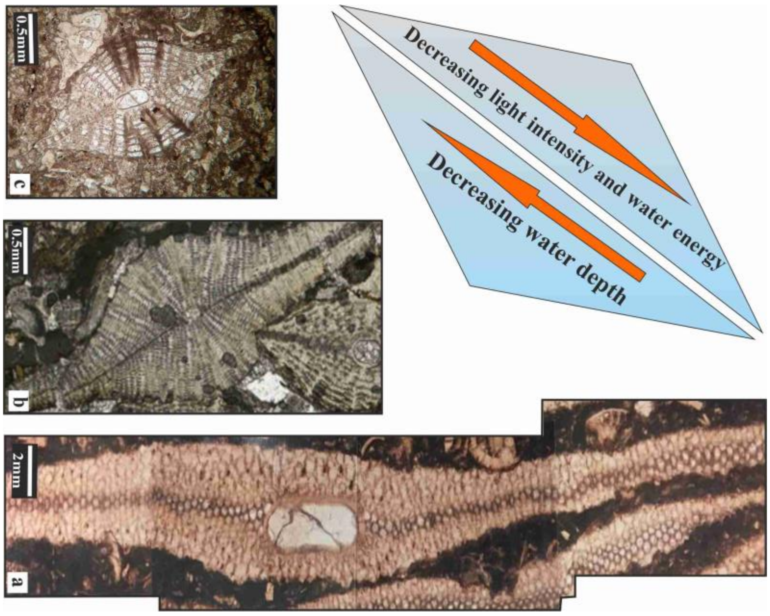

Fig 9. Note the ratio diameter/thickness (D/T) of *Lepidocyclina* test occurring in the Asmari Formation, and the growing trend indicating the water depth increase and the decrease in light intensity and water energy.

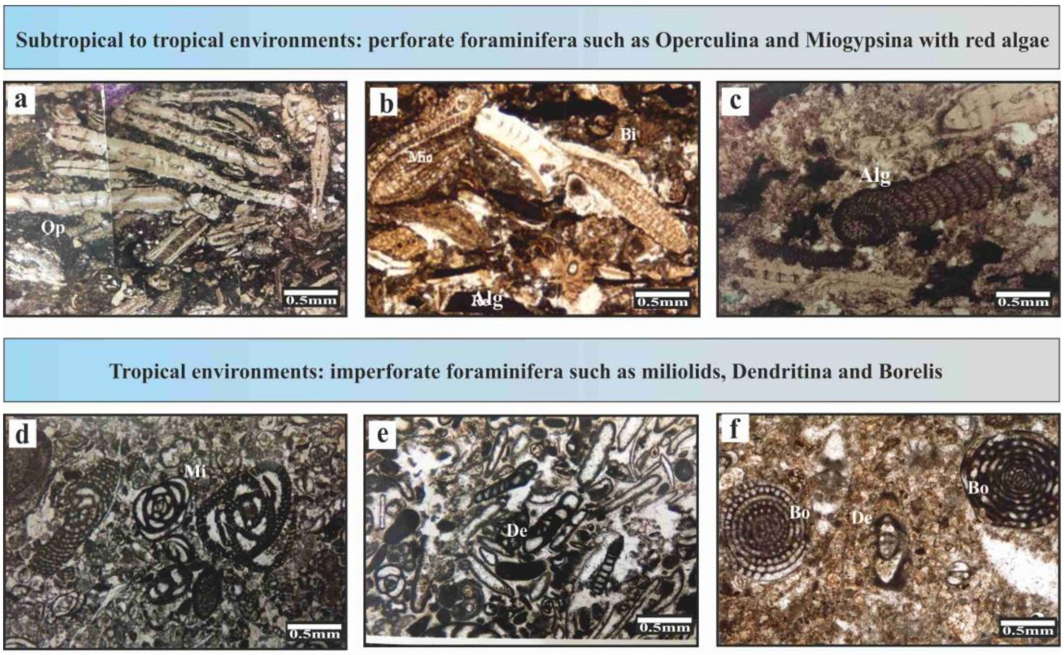

Fig 10. a, b, c These images document the sub-tropical to tropical environment with presence of red algae and foraminifers; d, e, f These images document tropical environments in which many imperforated foraminifers thrive (Op: *Operculina*, Alg: Algae, Bo: Borelis, De: Dendritina, Mio: Miogypsina, Mi: Miliolid).

8. Conclusions

Following these new well data, the Asmari Formation can be subdivided into 4 foraminiferal Assemblage Zones. (1) *Lepidocyclina-Operculina-Ditrupa* Assemblage Zone, (2) *Archaias asmaricus-Archaias hensoni-Miogypsinoides complanatus* Assemblage Zone, *(3) Miogypsina-Peneroplis farsensis–Elphidium* sp. 14 Assemblage Zone and (4) *Borelis melo curdica-Borelis melo melo* Assemblage Zone all indicating a Rupelian - Burdigalian age. Along this cored section were recognized 12 facies that can be gathered into five sedimentary environment types including restricted lagoon, open lagoon, shoal, slope, and basin settings. Based on the regional facies and stratigraphy, a deepening trend is observed in this shallow carbonate basin. Oncoids, pisoids, calciturbidite, slump structure, and aggregate grains are absent in the area. A homoclinal carbonate ramp setting is proposed for the deposition model of the Asmari Formation within the study area. Usually the carbonate sediments occur in shallow setting dated from Oligocene to Miocene. The foraminiferal assemblages in the lower part of the Asmari Formation document tropical to semi-tropical environments. Under such conditions, the presence of mesophotic and oligophotic conditions in the study area is also observed. Eroded imperforated foraminifers in the middle and upper parts of the Asmari Formation support shallow low depth and high salinity in these tropical areas, with oligophotic and mesophotic conditions.

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