Sequence stratigraphy and depositional environment of the Oligocene deposits at Firozabad section, southwest of Iran based on microfacies analysis

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Abstract

The Asmari Formation was deposited in the foreland basin of southwest Iran (Zagros Basin). Carbonate sequences of the Asmari Formation consist mainly of large benthic foraminifera along with other skeletal and non-skeletal components. Three assemblage zones have been recognized by distribution of these large foraminifera in the study area that indicate Oligocene age (Rupelian-Chattian). Absence of turbidite deposits, reefal belt and gradual facies changes indicate that the Asmari Formation was deposited in a carbonate ramp environment. Based on analysis of large benthic foraminiferal assemblages and microfacies features nine different microfacies have been recognized, which can be grouped into three depositional environments: inner, middle and outer ramp. Based on the microfacies analysis and sequence stratigraphic studies, two third-order sequences in Firozabad section were identified.

Keywords: *Asmari Formation, Oligocene, Zagros Mountains, Large benthic foraminifera, Carbonate ramp environment, Sequence stratigraphy.*

Introduction

The Oligo-Miocene Asmari Formation, the most famous carbonate reservoir in SW Iran, is a thick carbonate succession of the Tertiary deposits in Zagros foreland basin. The formation at its type section consists of 314 m of limestones, dolomitic limestones and argillaceous limestones (Motiei 1993).

Based on biostratigraphic data, the Asmari Formation is Oligocene in age in the Fars area, whereas it was deposited in Oligocene–Early Miocene in the Khuzestan area (James & Wynd, 1965) (Fig. 1). Towards the center of the basin, where the Asmari type section is located, the Asmari Formation with Early Miocene (Aquitanian-Burdigalian) age overlies gradationally the Pabdeh Formation (James &Wynd, 1965; Motiei, 1993).

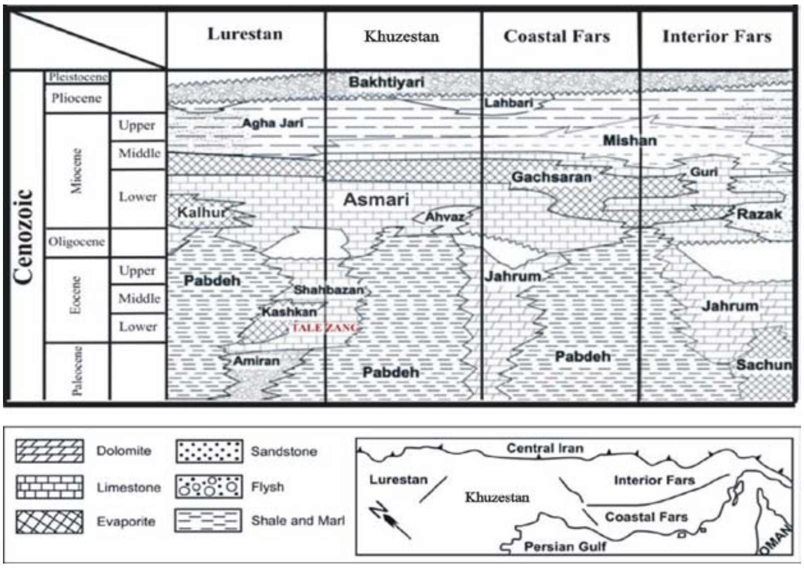


Fig. 1: Correlation chart of the Cenozoic deposits of southwest Iran (adopted from Ala 1982)

This paper deals with the Asmari outcrop and could be a supported research for better understanding of the formation in the adjacent subsurface sections. The present study focuses on the microfacies analysis, depositional environments and sequence stratigraphic framework of the Asmari Formation in Firozabad outcrop.

More recent studies of the Asmari Formation have been conducted on biostratigraphic criteria (Seyrafian *et al*., 1996, Seyrafian & Mojikhalifeh, 2005; Hakimzadeh & Seyrafian, 2007, Sadeghi *et al*., 2009, Laursen *et al*., 2009), microfacies and depositional environments (Seyrafian & Hamedani 1998, 2003, Seyrafian, 2000) and depositional environment and sequence stratigraphy (Vaziri-Moghaddam *et al*. 2006; Amirshahkarami *et al.*, 2007a and b; Ehrenberg *et al.*, 2007).

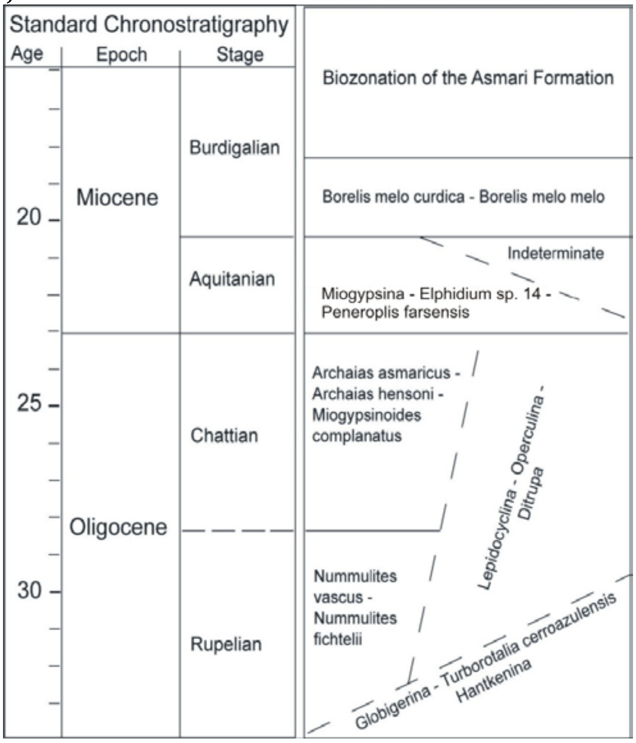
Methods and study area

More than 148 samples from Asmari Formation were studied. Petrographic studies were carried out for microfacies analysis and paleoenvironmental reconstruction of the Asmari Formation. Definition of microfacies is based on depositional texture, grain size, grain composition and fossil content. The classification of carbonate rocks followed the nomenclature of Dunham (1962). The study area is located about 16 km southwest Firozabad city. The section was measured in detail at 28°47′ N, 52°25‘ E (Fig. 2).

Biostratigraphy

Biostratigraphy criteria of the Asmari Formation

Table 1- Biozonation of Asmari Formation after Laursen *et al.*, 2009.



were established by Wynd (1965) and reviewed by Adams and Bourgeois (1967), both in unpublished reports. Ehrenberg (2007) applied the method of strontium isotope stratigraphy to date the Asmari Formation in four localities in SW Iran. Laursen *et al*. (2009) outlined biozonaton of Asmari Formation by means of strontium isotope data. Based on this biozonation, seven assemblage zones for Asmari Formation was recognized (Tab. 1). Three assemblages have been recognized in the Firozabad section. They are discussed in ascending stratigraphic as following:

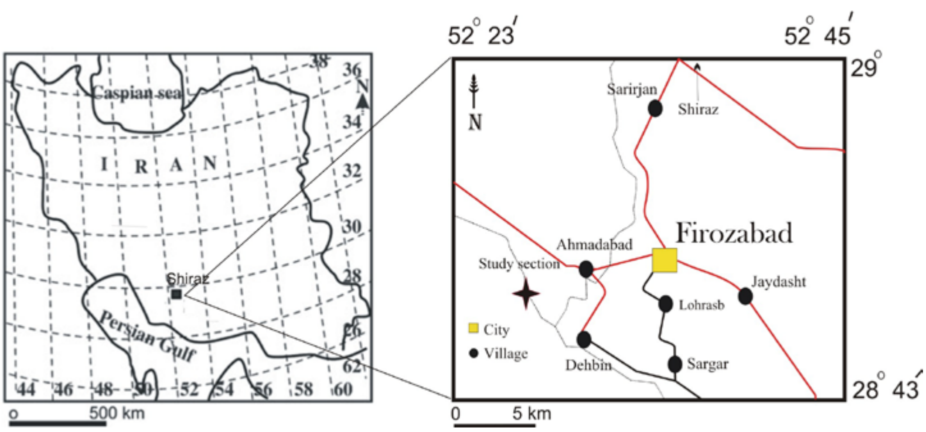


Fig. 2: Location map of the studied area in the Zagros region, southwest of Iran

Assemblage zone I: This assemblage begins at lower most part of Asmari Formation and extends through a thickness of 94 m. The most important foraminifera are: *Eulepidina elephantina, Eulepidina dilatata, Nephrolepidina tournoueri, Lepidocyclina* sp., *Nummulites fichteli- intermedius* group, *Nummulites vascus- incrassatus* group, *Operculina complanata, Heterostegina* spp., *Neorotalia viennoti* and globigerinids. This assemblage is correlated with *Nummulites vascus – N. fichteli* assemblage zone of Laursen *et al*., (2009) and attributed to Rupelian time.

Assemblage zone Π: This assemblage is recorded in thickness of 94-120 m. The most diagnostic species in the studied section include: *Lepidocyclina* sp., *Operculina* sp., *Planorbolina* spp., *Heterostegina* spp. and *Neorotalia viennoti*. The foraminirea correspond to the *Lepidocyclina – Operculina – Ditrupa* assemblage zone of Laursen *et al*. (2009). This assemblage is Chattian in age, based on its stratigraphic position which is above the assemblage I (with last occurrence of genus *Nummulites* at top of Rupelian).

Assemblage zone III: This assemblage occurs in thickness 120-170 m of the Asmari Formation and consists of: *Nephrolepidina* sp., *Eulepidina* sp., *Operculina* sp., *Archaias* spp., *Peneroplis* spp., *Borelis pygmaea, Austrotrillina* spp. This assemblage represents the *Archaias asmaricus - Archaias hensoni - Miogypsinoides complanatus* assemblage zone of Laursen *et al*., (2009) and indicates an age of Chattian (Upper Oligocene).

Microfacies analysis

The petrographic studies led to the identification of 9 microfacies. The described microfacies are then attributed to specific depositional environments. The general environmental interpretations of the microfacies are discussed in the following paragraphs.

Microfacies 1: Bioclast planktonic foraminifera wackestone-packstone (MF1) (Fig. 3-A)

The main components of this microfacies are planktonic foraminifera. Less common skeletal constituents include small benthic foraminifera and shell fragments. In some samples lamination were observed. This micofacies is mud-dominated. It is restricted to lower part of the studied section and is dominated by rhythmically alternating thin olive green to grey marly limestone and grey beds limestone. Nodular bedding is observed sporadically. Macrofossils are missing. The high amounts of micrite and lack of sedimentary structures reflect a relatively low turbulence environment suggest that this microfacies was deposited in calm, low energy hydrodynamic and deep normal salinity water (Scholle *et al*. 1983). The absence of photo symbiont-bearing taxa suggests that this microfacies was deposited below the photic zone (Cosovic *et al*., 2004). A similar microfacies was reported from outer ramp by Amirshahkarami *et al*., (2007a) from the Asmari Formation at Chaman-Bolbol Area.

Microfacies 2: Lepidocyclinidae nummulitidae planktonic foraminifera bioclast wackestone-packstone (MF2) (Fig. 3-B)

This microfacies is represented by association of planktonic foraminirera, large benthic oraminifera (lepidocyclinidae, nummulitidae) and fragments of echinoid with dominant mud-supported texture.Grey, thin bedded limestone with few intercalations of limy marlstone beds characterize this microfacies.

The precence of planktonic foraminifera accompanied by perforate foraminifera indicated a distal middle ramp depositional setting between the normal wave base and the storm wave base in the lower limit of the photic zone (Corda & Brandano, 2003; Romero *et al*., 2002). Vaziri-Moghaddam *et al*., (2006) considered similar facies as representative of a distal middle ramp environment. This microfacies was deposited on the shallower depth adjacent to microfacies 1.

Microfacies 3: Nummulitidae bioclast wackestone-packstone (MF3) (Fig. 3-C)

Nummulitidae (*Nummulites, Operculina, Hetrostegina*) with small size test (A form) are abundant biogenetic components in microfacies 3. Other bioclast are small debris of echinoids and bryozoans. Megascopically, it is medium-bedded limestone containing echinoid fragments.

A form dominated fossil communities are likely to have formed in the shallowest or deepest part of depth range. These two environments can be distinguished on the basis of the matrix and stratigraphic position (Beavington-Penny And Racey, 2004). The relatively low degree of fragmentation of the nummulitidae indicate that these deposits formed in the distal part of the middle ramp, well below the fair-weather wavebase since there are no signs of wave hydraulic turbulence in these microfacies.

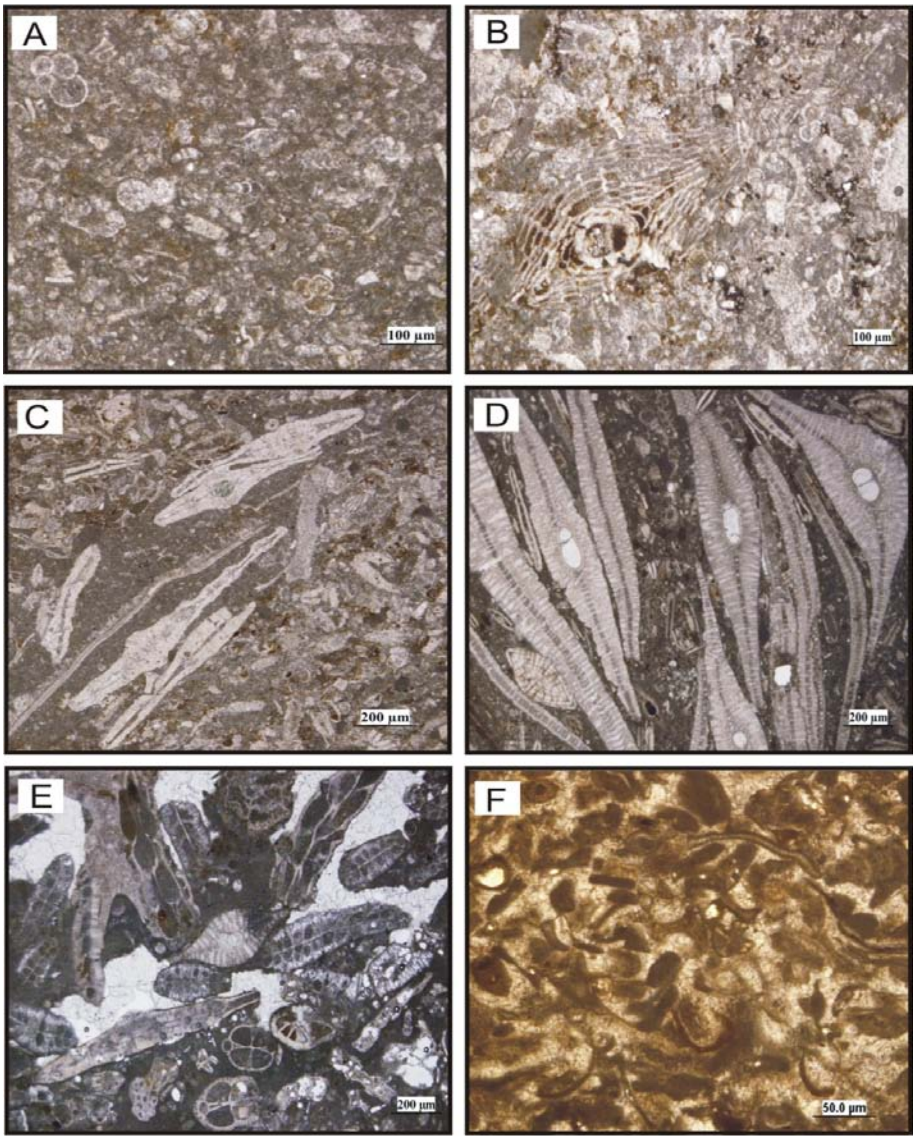


Fig. 3: Microfacies types of Asmari Formation A- MF1: Bioclast planktonic foraminifera wackestone-packstone B- MF2: Lepidocyclinidae nummulitidae planktonic foraminifera bioclast wackestone-packstone C- MF3: Nummulitidae bioclast wackestone-packstone D- MF4: Bioclast lepidocyclinidae nummulitidae packstone E- MF5: Lepidocyclinidae nummulitidae bryozoa packstone-grainstone F- MF6: Bioclast peloidal grainstone (XPL).

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Microfacies 4: Bioclast lepidocyclinidae nummulitidae packstone (MF4) (Fig. 3-D)

This microfacies is composed predominantly of large perforate foraminifera. Large benthic foraminifers are present as well-preserved test. Tests are dominated by large and flat lepidocyclinids and nummulitids. *Operculina*, *Heterostegina*, *Amphistegina*, *Eulepidina* and *Nephrolepidina* are among the most common genera. Fragments of corallinacean, echinoids and bryozoan are common to rare. It consists of grey medium bedded limestone with intercalations of grey marly limestone beds. Nodular bedding is observed. The fossil content of this microfacies (large perforate benthic foraminifera, echinoids and corallinacean) represents that this microfacies was formed in a low-medium energy, open marine environment (Romero *et al*. 2002), in the oligophotic zone (Pedley 1996; Brandano and Corda 2002, Corda and Brandano, 2003; Bassi *et al*., 2007). Flattened test shapes of lepidocyclinidae and nummulitidae suggest that this microfacies was deposited in the lower photic zone in the distal middle ramp (Hottinger, 1980, 1983; Hoheneger 1996, Hallock 1999; Reiss & Hottinger 1984; Leutenegger, 1984, Beavington-Penney & Racy 2004).

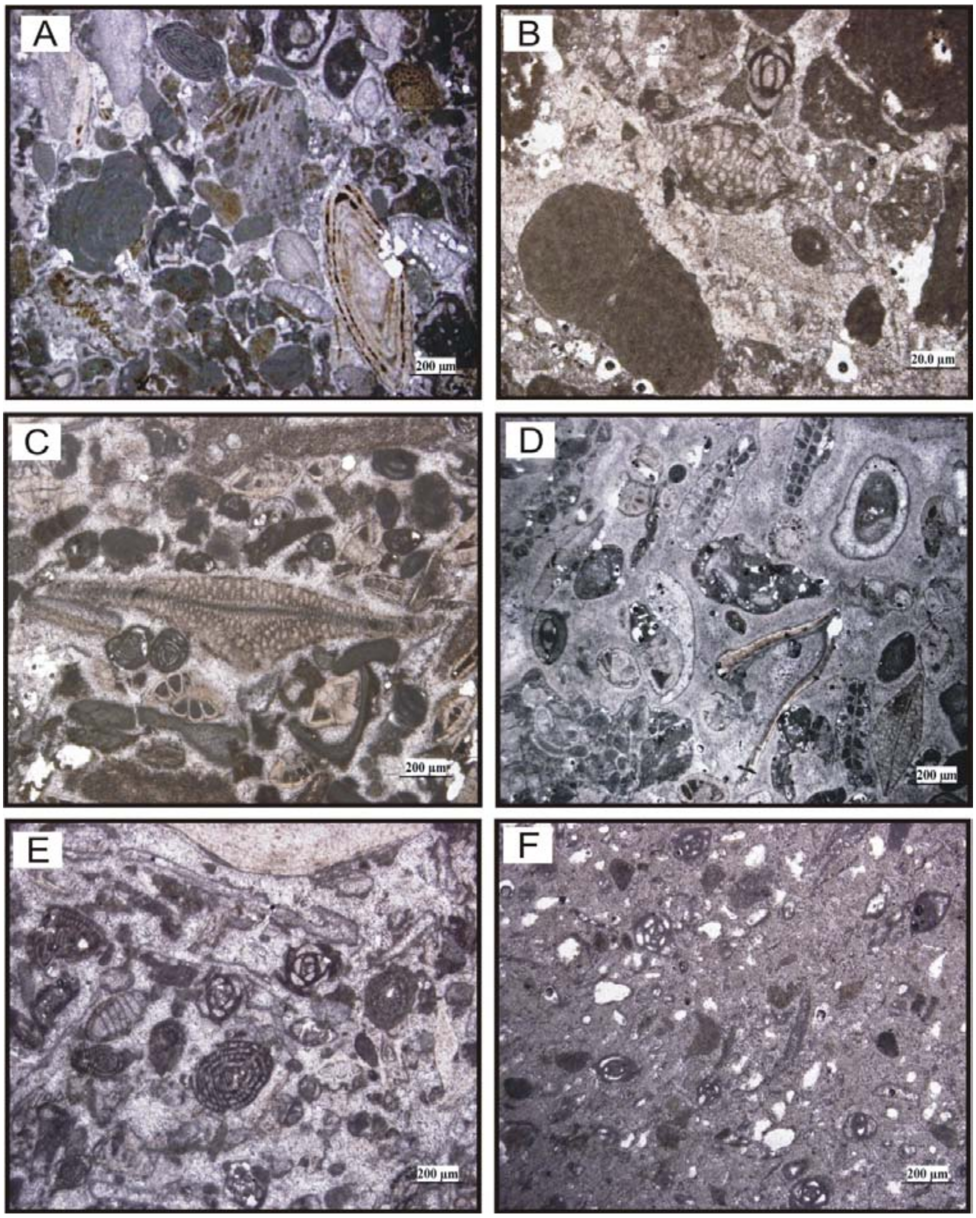

Fig. 4: Microfacies types of Asmari Formation A- MF7-a: Benthic foraminifera (perforate and imperforate) bioclast wackestone-packstone-grainstone B- MF7-b: *Norotalia* benthic foraminifera bioclast packstone C- (MF7-c): Benthic foraminifera corallinacea packstone D- MF7- d: Benthic foraminifea bioclast bryozoa packstone E- MF8: Imperforate foraminifera bioclast wackestone-packstone-grainstone F- MF9: Miliolid bioclast wackestone (XPL).

Microfacies 5: Lepidocyclinidae nummulitidae bryozoa packstone-grainstone (MF5) (Fig. 3-E). The major components of this microfacies are bryozoa and large benthic foraminifera with small and ovate tests (e.g. lepidocyclinidae, nummulitidae). These deposits include different textures ranging from packstone to grainstone. Megascopically, it is medium-bedded to thick-bedded limestone. Macrofossils are scarce, only rare poorly preserved bryozoa, and rare bivalves have been observed.

The presence of large foraminifera in this microfacies indicates deposition within the euphotic zone, because symbiont-bearing foraminifera are restricted to the euphotic zone (Romero *et al*., 2002; Corda and Brandano 2003; Bassi *et al*., 2007; Hohenegger, 2000). Prolification of perforates benthic foraminifera is indicative of normal marine conditions (Geel, 2000). This microfacies represent deposition on shallower environment than that of microfacies 4. The sediments with robust and lens specimens are reflecting shallower water than those containing larger and flat nummulitids and lepidocyclinids (Beavington-Penney & Racey 2004; Barattolo *et al*., 2007).

Microfacies 5 also shows evidence of enhanced nutrient levels. Decrease in hyaline foraminifera and abundance of suspension feeders (byozoans) confirm this interpretation.

Microfacies 6: Bioclast peloidal grainstone (MF6) (Fig. 3-F)

The sediments contain non-diagnostic founa and peloids. Bioclasts show micritic envelopes. Depositional texture is represented by grainstone. It consists of medium-bedded to thick-bedded grey to brownish limestone beds.

The sorting and grainy texture suggests a high energy environment for this microfacies. The sediments would have been deposited in a shoal environment which separating the open marine from more restricted marine environment (Flugel 2004).

Microfacies 7: Benthic foraminifera (perforate and imperforate) bioclast wackestone-packstone-grainstone (MF7-a) (Fig. 4-A)

This microfacies is composed of variable proportion of benthic foraminifera. Porcelaneous foraminifera such as miliolids (*Austrotrillina, Pyrgo, Quinqueloculina* and *Triloculina*), *Archaias* and hyaline foraminifera (*Heterostegina, Neorotalia* and lepidocyclinidae) are the most important foraminifera in this microfacies. MF7 include different texture ranging from wackestone to packstone to grainstone. Due to changes in the type of founa in some thin sections the name of this microfacies change to benthic foraminifera corallinacean packstone (MF7-b) (Fig. 4-B), *Norotalia* benthic foraminifera bioclast packstone (MF7-c) (Fig. 4-C), and benthic foraminifea bioclast bryozoa packstone (MF7-d) (Fig. 4-D). It is dominated by thick-bedded to medium-bedded olive green to grey limestone beds. Macrofossil assemblages consist of rare to common bryozoa, corallinacean, bivalves (such as oysters), and gastropods.

Co- occurrence of normal marine fauna and protected fauna indicate that deposition took place in the inner ramp environment (Taheri *et al*. 2008). In some samples increase in heterotrophs (bryozoans) and red algae with bioerosion suggest a change from oligotrophic condition to high level of nutrients (Brandano & Corda, 2002).

Microfacies 8: Imperforate foraminifera bioclast wackestone-packstone-grainstone (MF8) (Fig. 4-E). Megascopically, it consists of alternating grey thin-bedded limestone and nodular limestone. No macrofossils have been observed.

This microfacies is dominated by occurrence of imperforate foraminifera (miliolids, *Borelis, Archaias, Peneroplis and Austrotrillina*) and bivalve debris. The texture ranges from common wackestone and packstone to less common grainstone.

The occurrence of large number of porcelaneous imperforate foraminiferal tests may point to the depositional environment being slightly hyper-saline. Such an assemblage described to be associated with an inner ramp environment (Wilson, 1975, Flugel, 1982, 2004, Vaziri-Moghaddam *et al*., 2006, Brandano *et al*., 2008). Some porcelaneous imperforate foraminiferal (*Peneroplis* and *Archaias*) live in recent tropical and subtropical shallow water environments, hosting dinoflagellate, rhodophycean and chlorophycean endosymbionts (Lee, 1990). Due to presence of epiphytic foraminifera this microfacies could originated in sea-grass-dominated environments (Brandano *et al*. 2008).

Microfacies 9: Miliolids bioclast wackestone (MF9) (Fig. 4- F)

This microfacies is dominated by miliolids and bioclasts such as ostracod and bivalve. The matrix is fine grained micrite. Megascopically, it is thin bedded to nodular bedding containing bivalve fragments.

The predominance of mud-rich lithologies with oligotypic fauna (such as miliolids) and the presence of a low-diversity foraminiferal association indicate deposition in a low-energy, lagoonal environment with poor connection with open marine. Recent miliolids are euryhaline forms living in shallow, restricted/lagoonal environments with low turbulence thriving on soft substrates. When they present in great abundance may indicate nutrient-enriched conditions and/or extreme salinities (Geel, 2000).

Palaeoenvironmental model

Sedimentological and paleontological studies show that a ramp type carbonate platform sedimentary model can be fully applied to these ancient carbonate deposits (Read, 1982; Tucker 1985; Tucker & Wright, 1990) (Fig. 5). According to Burchette and Wright (1992), carbonate ramp environments are separated into inner ramp, middle ramp and outer ramp.

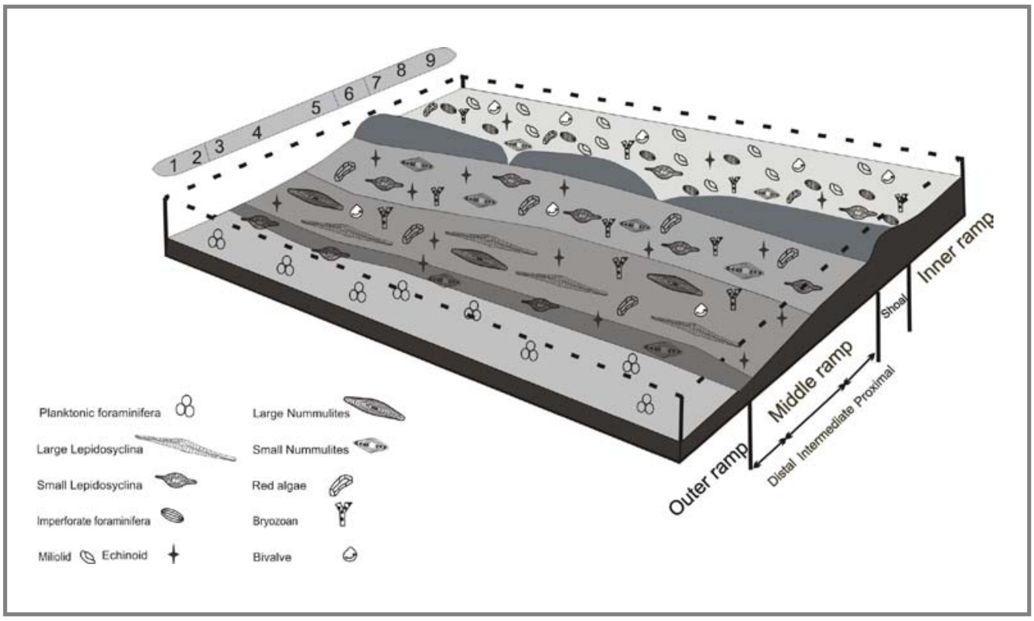

Fig. 5: Depositional model for the Asmari Formation in Firozabad area, Zagros Basin, SW Iran

Outer ramp microfacies are characterized by marly limestone lithologies. Wackestones predominate with abundant planktonic foraminifera. The presence of mud-supported textures and the apparent absence of wave and current structures suggest a low energy environment below storm wave base (Burchette & Wright, 1992). The basinal microfacies occurs in the lower part of the succession.

The middle ramp setting is characterized by association of large foraminifera with perforate wall. The proximal middle ramp dominated by small and ovate perforaate foraminifera (MF5). Large, flat and the whole tests of perforate foraminifera are the dominant microfauna of the intermediate middle ramp (MF4), probably because they were the best adopted fauna to the palaeoenvironmental conditions such as low hydrodynamic energy, lower limit of the photic zone, oligothrophy and normal salinity (Leutenegger, 1984; Romero *et al*., 2002). The distal mid-ramp (MF3) is differentiated from the shallower depth by a greater amount of micritic matrix and decrease in the flatness and size of the perforate foraminifera.

Inner ramp deposits represent a wider spectrum of marginal marine deposits, indicating high-energy shoal, open lagoon and protected lagoon. Shoal microfacies is characterized by bioclastic grainstone. Skeletal grains originate mainly from open-marine fauna. Presence of well-sorted grains and lack of mud indicate high-energy conditions (Wilson, 1975; Flugel, 2004). Restricted shallow subtidal environments in the inner ramp are indicated by low-diversity skeletal fauna, abundant of imperforate foraminifera (miliolids and *Archaias*) and lack of subaerial exposure features (Reis and Hottinger, 1984; Hallock, 1984, 1988; Buxton and Peddely, 1989; Romero *et al*., 2002; Barattolo *et al*., 2007). Semirestricted shelf lagoon microfacies in the inner ramp are differentiated from restricted shallow subtidal microfacies by the diversity of skeletal fauna and co-occurrence of imperforate and perforate foraminifera.

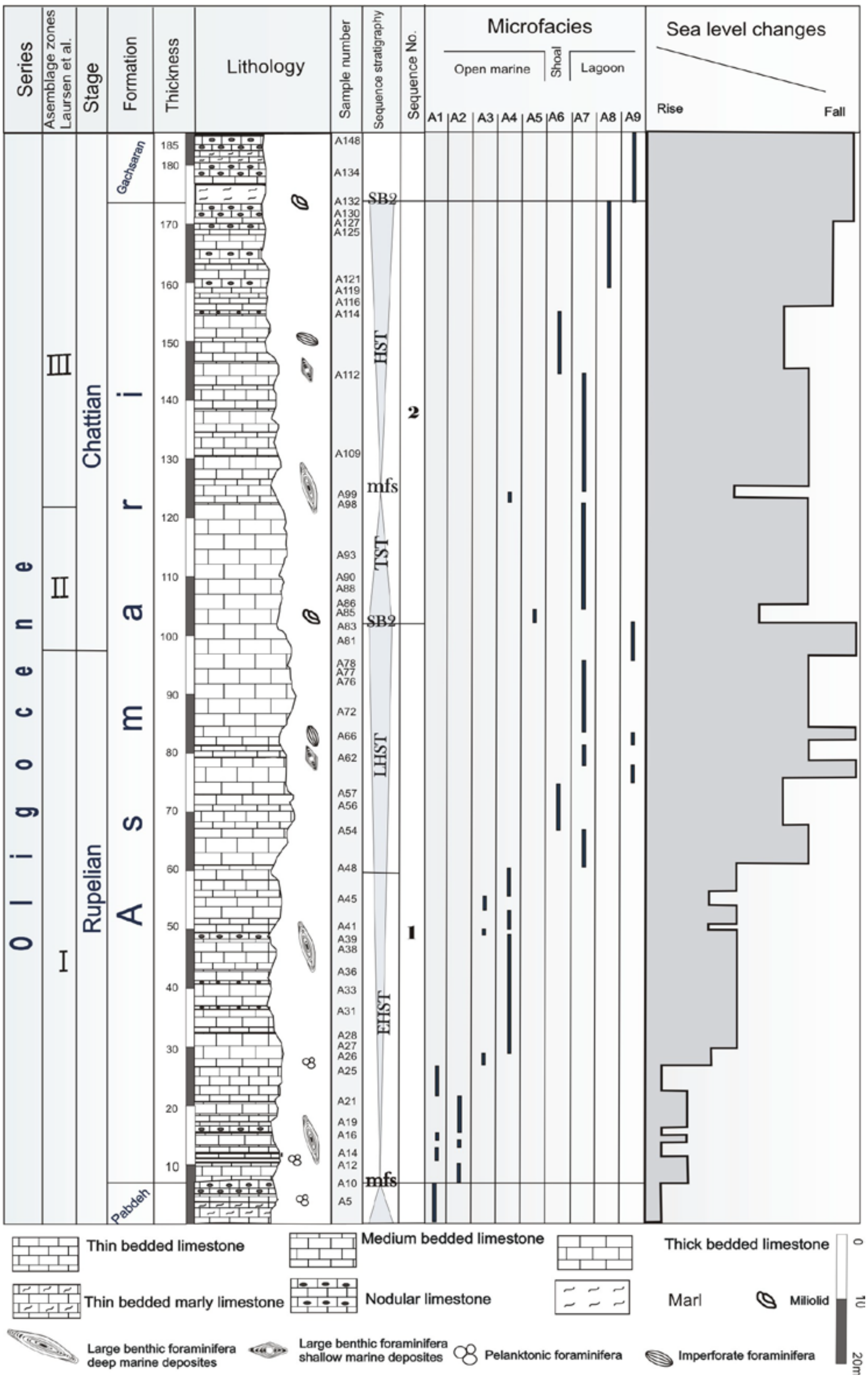

Fig. 6: Vertical microfacies distribution and sequences of the Asmari Formation at Firozabad section, Zagros. TST: Transgressive Systems Tract; HST: Highstand Systems Tract; MFS: maximum flooding surface; SB2: Sequence boundary type 2

Sequence strtigraphy

Sequences are defined as a conformable succession of genetically related strata, bounded at the top and bottom by unconformities and/or their correlative conformities (VanWagoner *et al*., 1988, 1990).The unconformities are defined as surfaces of erosion or non-deposition and represent a significant time gap. The major control on deposition is relative sea-level change, determined by rates of eustatic sea-level variation and tectonic subsidence. Particular depositional system tracts are developed during specific phases of the sea-level change's curve: lowstand (LST) transgressive (TST), and highstand (HST) systems tracts.

In marine shelf environments it is sometimes difficult to distinguish the different systems tracts of a depositional sequence (Vail *et al*., 1984; Posamentier & Vail, 1988; Sarg, 1988). This is particularly true when dealing with homogenous lithology, intermittent data irregular dating elements as no real isochrones can be depicted with certainty. Therefore, it is most helpful to use the various markers of high and low sea-level phases contained within strata to confirm interpretations. In this context, benthic foraminifera seem to provide particularly reliable data as they are very sensitive to any change in environment. The validity of this concept has been checked by studying the distribution of benthic foraminiferal associations in deposits where the cycles of eustatic rise and fall of sea-level were already well known (Cubaynes *et al*., 1989).

In this study, distribution of foraminifera and facies data was used for sequence stratigraphic interpretation. The studied succession can be framed in a sequence stratigraphic context. In the present paper, two shallowing upward third-order sequences are identified.

Sequence 1: The sediments of sequence 1 are Rupelian in age. This sequence is 102 m thick and its microfacies association can grouped into Transgrassive and Highstand Systems Tracts. The lower part of sequence 1 (TST) is characterized by an alternation of limestone and marly limestone with planktonic foraminifera. The mfs is marked by a deep marine microfacies (planktonic foraminifera wackestone) and separates TST from HST. Wackestone and packstone with perforated large benthic foraminifera overlie the mfs. These sediments are interpreted as the Early HST. Early HST deposits are mostly composed of shallow open marine microfacies. The lagoonal deposits with abundant imperforate and perforate benthic foraminifera indicate late HST deposits. The late HST shows a trend toward more protected sediments (wacke-packstone with imperforate foraminifera), expressing a filling of the accommodation space. The boundary between seq.1 and seq.2 is put at the top of the MF 9 (Fig. 6). The top boundary of this sequence (SB2) is dated as latest Rupelian, just in the Rupelian–Chattian boundary. This sequence boundary seems to correlate with the sequence boundary TB1.1 (30.0 Ma) of Haq *et al*., (1988) at the Early Oligocene/Late Oligocene boundary, 28.4 Ma, Hardenbol *et al*., (1998) and with an isotopic event referred to as OCi-1 at 28.4 Ma (Abreu & Haddad, 1998).

Sequence 2: The thickness of sequence 2 is nearly 70 m. Deepening-upward microfacies trends (TST) of sequence 2 is indicated by change from restricted lagoonal microfacies to open lagoon and open marine facies. The mfs of this sequence was marked by packstone with perforated large benthic foraminifera. The upper part of sequence (HST) is characterized by gradual microfacies changes from open lagoonal to protected environments. Such changes reflect decreases in water-depth. The sequence boundary is characterized by wackestone with low diversity imperforate foraminifera and is interpreted as a SB2 type. This sequence boundary seems to correlate with the sequence boundary 25.1 Ma Van Buchem *et al*., (2010) TB1.3 (26.5 Ma) of Haq *et al*., (1988) in the Late Oligocene, 25.4 Ma, Hardenbol *et al*. (1998) and with an isotopic event referred to as OCi-3 at 25.2 Ma (Abreu & Haddad, 1998).

Correlation of our interpreted sea-level curve during deposition of the Asmari Formation with the worldwide sea level curve of Haq *et al*., (1988) for the Ruprlian-Chattian shows geometric similarities. However, some differences are related to the regional geological setting.

Haq *et al*., (1988) presented three 3rd-order depositional sequences during the Rupelian-Chattian time, while in the study area we identified two 3rd-order cycles. We believe that these differences are related to regional tectonic settings and sediment supply of the study area.

Conclusion

The Asmari Formation at the study area is subdivided into 9 microfacies that are distinguished on the basis of their depositional textures, petrographic analysis and fauna. In addition, three major depositional environments were identified in the Asmari Formation. These include shelf lagoon, shoals and open marine environmental settings which are interpreted as a carbonate ramp. Two third-order sequences are identified based on deepening and shallowing patterns in microfacies and distribution of Oligocene foraminifera.

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