Microfacies and depositional environment of the Asmari Formation of the Bandar-pol anticline, Zagros Basin, South of Iran

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Abstract:

The Asmari Formation (Oligocene-Miocene), a thick carbonate succession of shallow-water carbonates of the intrashelf basin deposits of Zagros Mountains, has been studied to determine its microfacies and paleoenvironments. In the study area (Bandar-pol anticline), the Asmari Formation is subdivided into nine microfacies that are distinguished by petrographic analysis on the basis of their depositional textures and fauna. Consequently, five major depositional environments were identified in the formation. Based on the paleoecology and lithology, five distinct depositional settings can be recognized: tidal flat (MF1), lagoon (MF2-3-4), shoal (MF5), restricted (MF6) and open marine (MF7-8-9). Based on the environmental interpretations, a ramp consisting of inner and middle parts prevails.

Keywords: Asmari Formation; Bndar-pol anticline; Microfacies; Carbonate ramp.

1. Introduction:

Cenozoic carbonate rocks are a fundamental link between modern depositional environments and those of the older stratigraphic record (Rahmani et al., 2009). The Asmari Formation was named after the Kuh-e- Asmari in Khozestan province by Busk and Mayo (1918) and referred to as a sequence of Cretaceous-Eocene age. The Asmari Formation (Euphrates Formation in Iraq) contains some of the largest oil reservoirs in the world (Alavi, 2004). Lithologically, the Asmari Formation, at the type section, consists of 314m of mainly limestones, dolomitic limestones and argillaceous limestones in the Zagros (Motiei, 1993). The Formation is mainly consists of carbonate (limestone and dolomite) but it also has a mixed siliciclastic/carbonate (Ahwaz member; fluvio-deltaic siliciclastic deposition in Khuzestan) and evapoitic successions (Lurestan) (Motiei1993 and Vaziri Moghadam et al., 2010). Interest in the study of the stratigraphy and sedimentary environment of the Asmari Formation has been largely motivated by the exploration for oil and gas.

The Formation was studied in detail and formally defined by James and Wynd (1965). More recent studies based on subsurface data and outcrops of the Asmari Formation were carried out by Adams and Bourgeois (1967), Wells (1967), Seyrafian (1981), Kalantari (1986), Jalali (1987), Seyrafian et al. (1996), Hamedani et al. (1997), Seyrafian (2000), Seyrafian and Hamedani (1998, 2003), Nadjafi et al. (2004), Seyrafian and Mojikhalifeh (2005), Vaziri-Moghaddam et al. (2006), Amirshahkarami et al. (2007a, 2007b), Ehrenberg et al. (2007), Hakimzadeh and Seyrafian (2008), Sadeghi et al. (2009), Mossadegh et al. (2009), Laursen et al. (2009) and Sahraeyan et al. (2013). These authors had reviewed the stratigraphy, sedimentary facies, lithological characteristics and microfaunal assemblages of the Asmari Formation. They suggested that the lower Asmari Formation was deposited in more open-marine higher-energy environments. While the middle-upper Asmari Formation developed in more protected settings, which periodically became hypersaline as indicated by the presence of dolomite and anhydrite (Aqrawi et al., 2006). The main objectives of this research are description, interpretation of the stratigraphy, biostratigraphy and microfacies of the Asmari Formation in addition to the depositional environments of the Formation. There are not available studies or reports on the facies analysis and sedimentary environments of the Asmari Formation in the Bandar-pol Mountain outcrop.

2. General geology of the study area:

The Asmari Formation was deposited in a northwest- southwest oriented foreland Zagros Basin which extended from northeastern Syria through northern and northeastern Iraq into southwestern Iran. The Zagros Basin was a part of the stable supercontinent of Gondwana in Paleozoic time and a passive margin in Mesozoic time and became convergence orogene in Cenozoic Time (Bahroudi et al., 2011). In Jurrasic time, Orogenic movement caused Zagros Basin divided into several basins (Fig.1). In the southwestern part of the Zagros basin, the Asmari Formation overlies the Pabdeh Formation (Jaddala Fiormation in Iraq), whereas in the Fars and Lurestan regions it covers the Jahrum (Pila Spi in Iraq) and Shahbazan formations (Fig. 2). Although the lower part of the Asmari Formation interfingers with the Pabdeh Formation in the Dezful Embayment (Motiei, 1993), its upper part covers the entire Zagros basin. The maximum thickness of the Asmari Formation is found in the northeastern corner of the Dezful Embayment. This research involves two stratigraphic sections from the Asmari Formation in the Zagros fold belt (Fig. 1) of the Fars (coastal) areas in south Iran (Bandar-pol anticline) (Fig. 1 and 2). The study area is located about 12 km Bandar-pol and 78 km south-west of Bandar Abbas city. The section was measured in detail at 55° 42′ E and 27° 32′ N. (Fig. 1).

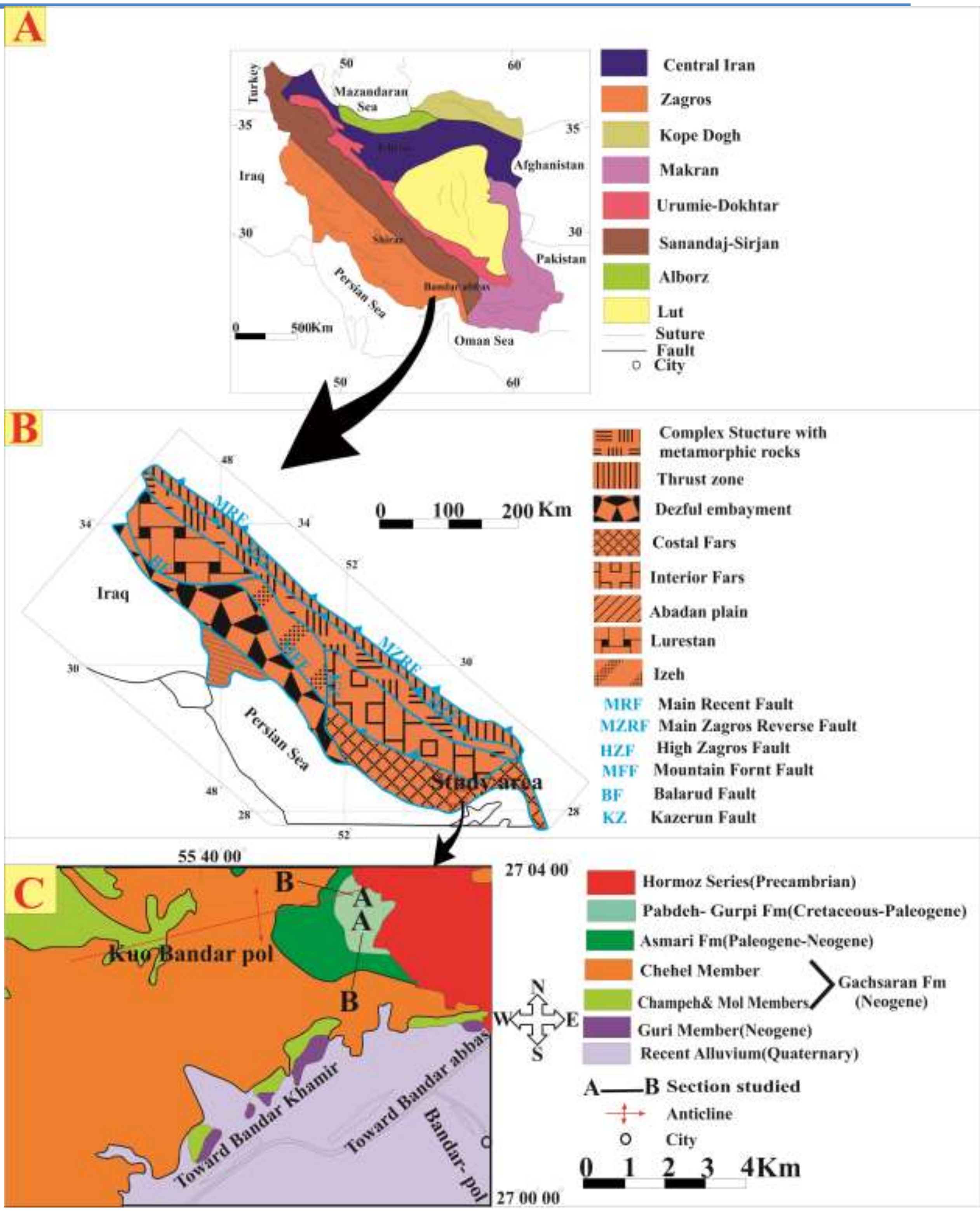

Fig. 1: A- Location and geological map of the study area(adopted from Heydari, 2008). B- Subdivisions of the Zagros province and location of the Coastal Fars Zone in Zagros basin (adapted from Farzipour-Saein et al. 2009). C- Geological map of the study area, Bandar-pole Anticline, south Iran (with slightly modified after Fakhari, 2000).

3. Methods and study area:

Two sections of the Asmari Formation were measured bed by bed, and sampled in areas and lithologically investigated. The sections were described in the field, including their weathering profiles, facies and bedding surfaces. Fossils and facies characteristics were described in thin sections from 66 samples. Foraminiferal biostratigraphy and microfacies determination are based on thin-section examination. The lithology and the microfacies types were described according to the schemes proposed by Dunham (1962) and Embry and Klovan (1971). Facies definition was based on the microfacies characteristics, including depositional texture, grain size, grain composition, and fossil content (Flugel, 2010).

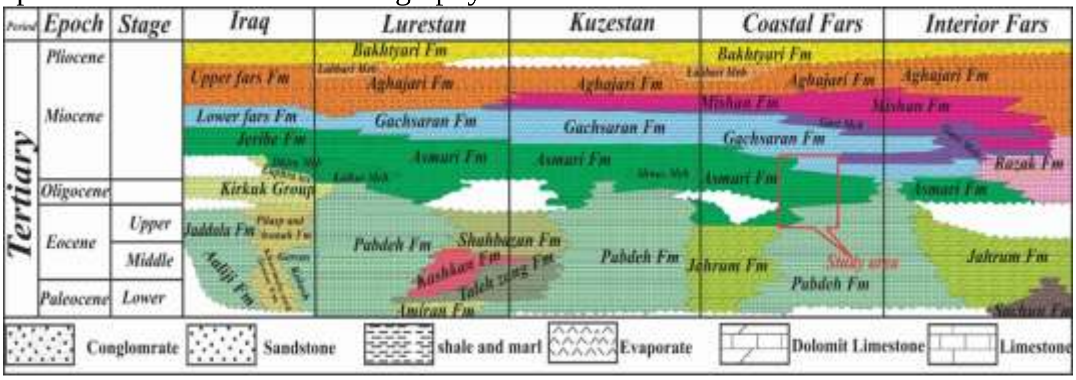

Fig.2: Stratigraphic correlation chart of the Tertiary units of Iraq, Zagros Range (Iran),(with slightly modified after Motiei, 2001 and Bordenave, 2003).

4. The stratigraphical section:

In the study area the thickness of the Asmari Formation is 225 m. The lower boundary of the Asmari Formation is exposed and underlain by the Pabdeh Formation and the upper boundary is exposed and overlain by the Gachsaran Formation (Lower Fars in Iraq) (Fig. 3). The Asmari Formation in the study area consists of six units. *Unit 1:* has a thickness of 33 m consists of medium to thick-bedded or massive dark gray limestone (Fig. 3) and overlies the Pabdeh Formation. The rocks contain skeletal grains of various groups, including calcareous algae, nummulites and bivalves. *Unit2:* with a thickness of 9 m and is composed of dark gray to green marl. *Unit 3:* with a thickness of 55 m is light grey of thick to medium-bedded limestone with large fossils. Most of the rocks were originally composed of coarse-grained carbonate. The lower limestone generally appears thick bedded with a packstone texture. Common fossil constituents are foraminifers, nummulites, and echinoderms. *Unit 4:* with a thickness of 71 m consists of thin to very thin-bedded limestone with a packstone texture and with intercalation of thin to medium bedded, grey to green marl. Common fossil constituents are calcareous algae, bivalves, coral and bryozoa. Upward, the packstone facies tends to dominate, and fossil components decrease in both abundance and diversity. *Unit 5:* has the thickness of 31 m and composed of grey to light green marl and fossil foraminifers with alternation of grey, thin bedded lime stone. *Unit 6*: with a thickness of 32 m and composed of thick to medium bedded limestone and underlies the Gachsaran Formation with nummulites and gastropoda.

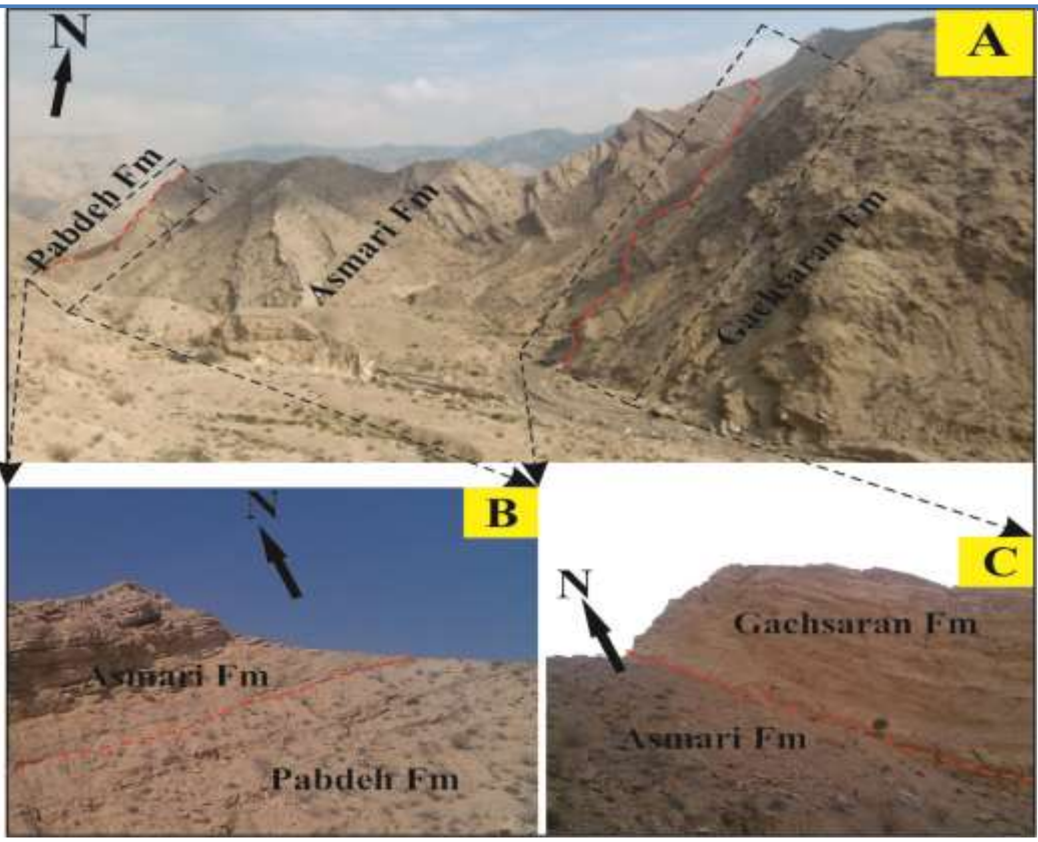

Fig.3: - General view of the studied section (A), lower boundary of Asmari Formation with Pabdeh Formation, which is transitional (B), and (C) upper boundary of Asmari Formation with Gachsaran Formation it is seems Paraconformity.

5. Biostratigraphy:

A biostratigraphic zonation of the Asmari Formation were established by Wynd (1965) and reviewed by Adams and Bourgeois (1967) in unpublished reports. Biozonation and age determinations, based on strontium isotope stratigraphy, are recently established for the Asmari Formation by Laursen et al. (2009). Based on this biozonation, seven assemblage zones of the Formation were recognized. Considering biozonation proposed by Laursen et al. (2009), the following foraminiferal assemblages were identified for the study area. Four assemblages have been recognized in the study area (Fig. 7). They are discussed in ascending stratigraphic as following:

Assemblage zone 1: This assemblage begins at lower most part of Asmari Formation and extends along the thickness of 115 m. The most important foraminifera are: nummulites fichteli- intermedius group, nummulites vascus- incrassatus group, 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 2: This assemblage is recorded along the interval of 115-145 m. The most diagnostic species in the studied section include: lepidocyclina sp., operculina sp and neorotalia viennoti. The foraminirea correspond to the lepidocyclina – operculina – ditrupa assemblage zone of Laursen et al. (2009).

Based on its stratigraphic position, this assemblage is Chattian in age, which is above the assemblage 1 (with last occurrence of genus nummulites at top of Rupelian).

Assemblage zone 3: This assemblage occurs in thickness 145-192 m. The most important foraminifera are: lepidocyclina sp., nephrolepidina sp., triloculina trigonula and miliolids. This assemblage is correlated with lepidocyclina-operculina-ditrupa assemblage zone of Laursen et al. (2009) and is attributed to the Chattian time.

Assemblage zone 4: This assemblage zone which is 30 (192-225) m thick and mainly consists of miogypsina sp., elphidium sp. 14, peneroplis sp., miliolids, and neorotalia viennoti. This assemblage corresponds to the miogypsina–elphidium sp. 14- peneroplis farsensis assemblage zone of Laursen et al. (2009). The assemblage is considered to be Aquitanian in age.

6.Microfaciesdescription and depositi-onal environment:

The primary depositional features are discernible in thin sections of the rock, including textures, microfossils and sedimentary structures. These features led to the recognition of nine microfacies. The contact with the underlying Pabdeh Formation is transitional and conformable, and the upper contact with Gachsaran Formation is paraconformable. Therefore, in this study, some samples from two Formation have been studied too (Fig. 7). The general environmental interpretations of the microfacies are discussed in the following paragraphs.

1) MF1: Stromatolite boundstone

This microfacies is formed by stromatolitic laminae, locally showing a fenestral fabric. The open space in the fenestral fabrics in a micritic matrix, are filled with sparite (Fig. 4B). The cyanobacteria with their filamentous features trapping and binding of sedimentary particles produced a laminated sediment or stromatolite (Fig. 4A). Bioclasts are lacking, fenestrate structures are well developed, and evaporate psuedomorphs are rare. The fine grained nature of this facies, lack of fauna, and presence of fenestral fabric suggest that deposition occurred in a tidal fat environment in a warm and arid region (Flugel, 2010). Modern stromatolites are most common in shallow, intertidal and supratidal zones, although they may occur under subtidal conditions (Aguilera-Franco et al, 2004).

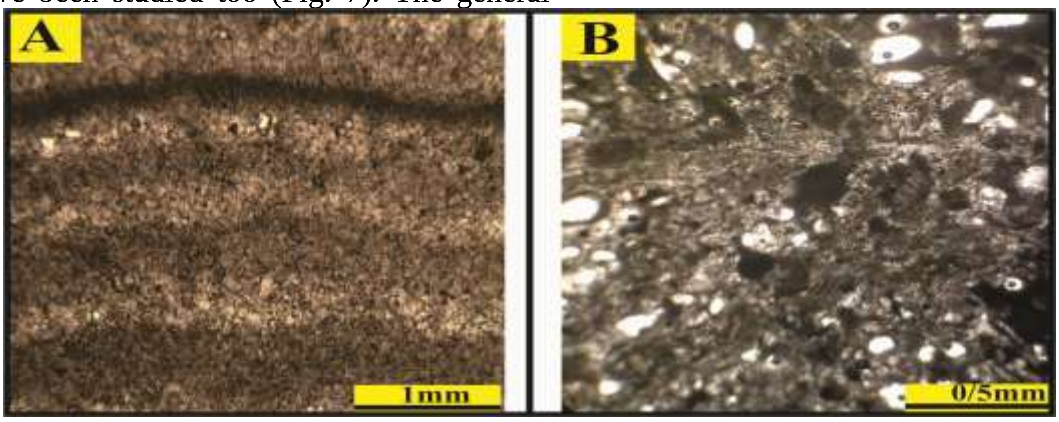

Fig.4: Photomicrographs (A, B) of the Stromatolite boundstone (MF 1).

2) MF2: Peloid miliolids bioclast wackestone-packstone

The main components grain of this microfacies is peloids and benthic foraminifera, fragments of macrofossils (Fig. 5A). Textures are dominantly packstone, but range from wackestone. Benthic foraminifers are common and include miliolids (Fig. 5B). Other common bioclasts constituents include bivalve and gastropod fragments. Rare algae is also present. The grains are poorly to medium sorted, are fine to medium size and vary from sub-angular to semi-rounded. This microfacies represents the shallowest upper part of the photic zone, with very light, highly translucent and soft muddy substrate (Vaziri-Moghaddam et al., (2006); Bassi et al., (2007)). This facies was deposited in a shelf lagoon. Nebelsick et al. (2001) and Vaziri-Moghaddam et al. (2006) considered similar facies representative of a shelf lagoon.

3) MF3:Miliolid-intraclast-bioclast packstone

The main biotic components consist of miliolids and shell fragment (Fig. 5C). Intraclasts are also present. Textures reflect poorly sorted packstone–grainstone. Some of the grains have been partially micritized. Concurrent of normal marine bioclasts and lagoonal biota with intraclasts suggest deposition at the lagoonal (Hallock and Glenn, 1986) and the textural characteristics and abundance of miliolids and intraclasts (Fig. 5D) suggest that the sedimentary environment is a lagoon with a nearby tidal flat.

4) MF4:Bioclast, nummulitida, miliolids wackestone-packstone

This facies is composed of wackestone–packstone with micritic bioclastics. Skeletal grains include echinoid, nummulitidae (operculina and heterostegina) and miliolids (Fig. 5E). Romero et al., (2002), Rasser and Nebelsick (2003), Corda and Brandano (2003) and Vaziri- Moghaddam et al. (2006) considered the similar facies are representative of a shelf lagoon. Small to medium-sized nummulitids in association with smaller miliolids indicate that sedimentation took place in a shelf lagoon (Fig.5F). A similar facies with imperforated foraminifers, perforated foraminifers (operculina, heterostegina,) was reported from inner ramp of the Miocene sediments of the central Apennines (Corda and Brandano 2003) and from Early Oligocene deposits of the Lower Inn Valley (Nebelsick et al. 2001).

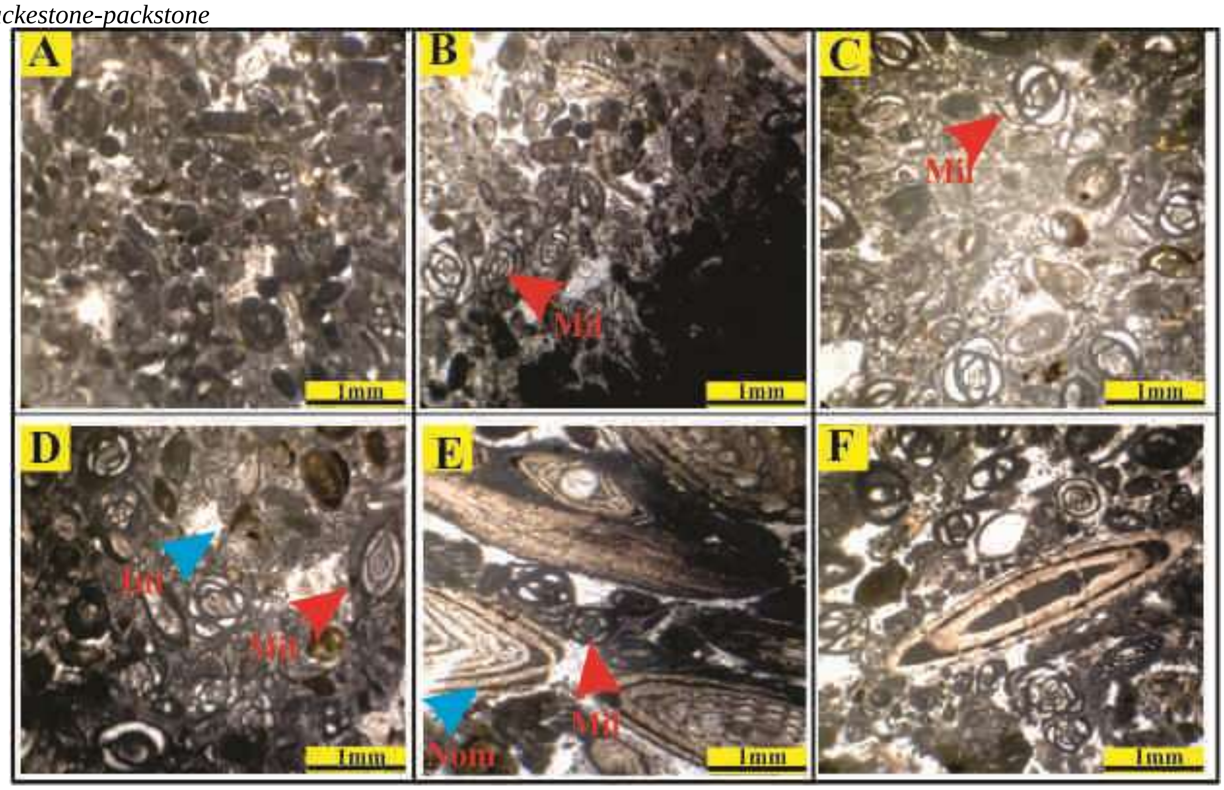

Fig.5: (A) and (B) Peloid miliolids bioclast wackestone-packstone(MF2): (C) and (D) Miliolid-intraclast-bioclast packstone (MF3): (E) and (F) Bioclast nummulitida miliolids wackestone-packstone (MF4):. Abbreviations:Mil: Miliolide, Int: Interclast, Nom: Nummulitida.

5) MF5: Bioclast grainstone/packstone

This microfacies is characterized by a high abundance of shell fragments (mainly mollusk debris). Bioclasts of this microfacies belong to gastropods, bivalves, algae, benthic foraminifers and echinoderms (Fig.6A, B).

This facies has a packstone–grainstone texture. The features of these facies indicate moderate to high-energy shallow water conditions with significant movement and reworking of bioclasts. In accordance to the standard microfacies types described by Wilson (1975) and Flugel (2010), microfacies MF5 is interpreted as a shoal environment above the normal wave base which was located at the platform margin, separating the open-marine from the more marine environments.

6) MF6: Bioclast peloidal grainstone

Compositionally, these are bioclastic-peloidal grainstone with bivalve and echinoid fragments and miliolids. Bioclasts show micritic envelopes. Usually, the allochems are well sorted (Fig.6C). 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 separates the open marine from more marine environment (Flugel, 2010).

7) MF7: Coral boundstone

This facies is composed of tabular, massive and domal coral colonies. Tabulata corals reach to 55% and they include fragments of thamnoporoids. Spaces between clasts and skeletons are usually occupied by micrite, but some zones show moderate percentage of sparite (Fig.6D). Coral boundstone locally presents a lower density of bioclasts and shows many encrusted layers (bryozoans and algae). Fragmentation indicates high energy, but dominance of micrite indicates that the high level of energy was not constant. Bryozoans probably occurred during calm phases (Kershaw and Brunton, 1999). It was probably a patch reef in initial stage of development, affected by periodical storms and deposited in an open marine. This microfacies is interpreted to be formed by in-situ organisms as an organic patch reef (Bioherm). A similar microfacies was reported by Wilson (1975), Riding et al. (1991) and and Flugel (2010).

8) MF8: Nummulitidae bioclast wackestone–packstone

This facies is characterised by coarse grained wackestone–packstone dominated by nummulitidae are abundant biogenetic components in microfacies MF9. Fragmentation of larger foraminifera is common and they are distributed irregularly among the larger foraminifera (Fig.6). The change in shape of test larger perforate foraminifera with depth has been documented in the Cenozoic carbonate successions (Nebelsick et al. (2005); Barattolo et al. (2007); Bassi et al. (2007)). The sediments with robust and lens specimens are reflecting shallower water than those containing larger and flat nummulitids and discocyclinids (Beavington-Penney and Racey (2004); Barattolo et al. (2007)). The relatively low degree of fragmentation of the nummulitidae and rare planktonic foraminifers indicate that these deposits formed in the distal part of the middle ramp and shallower environments at the probably near high energy shoals.

9) MF9:Bioclast nummulitidae, lepidocyclinidae wackestone–packstone

This microfacies is composed of grain–supported texture with abundant larger benthic foraminifera. This microfcies has a fine grained matrix. The foraminiferal assemblage is represented by numerous larger benthic perforate foraminifera such as lepidocyclinidae and nummulitidae (Fig.6H,I). Among the larger foraminifera, the nummulitidae are represented by operculina. Other bioclasts include bryozoa, mollusca, echinoid, and small benthic foraminifera. This facies is most prominent in upper parts of the Asmari Formation. This interpretation is supported by the abundance of typical open marine skeletal fauna including fat and large nummulitidae, bryozoa, and echinoidea (Amirshahkarami et al., 2007b). The fossil content of microfacies MF10 (large and flat nummulitidae) clearly identifies them as open marine deposits (Geel, 2000). The presence of large foraminifera in this microfacies indicates deposition within the euphotic zone, because symbiont-bearing foraminifera are to the euphotic zone (Romero et al. (2002), Corda and Brandano (2003), Bassi et al., (2007)).

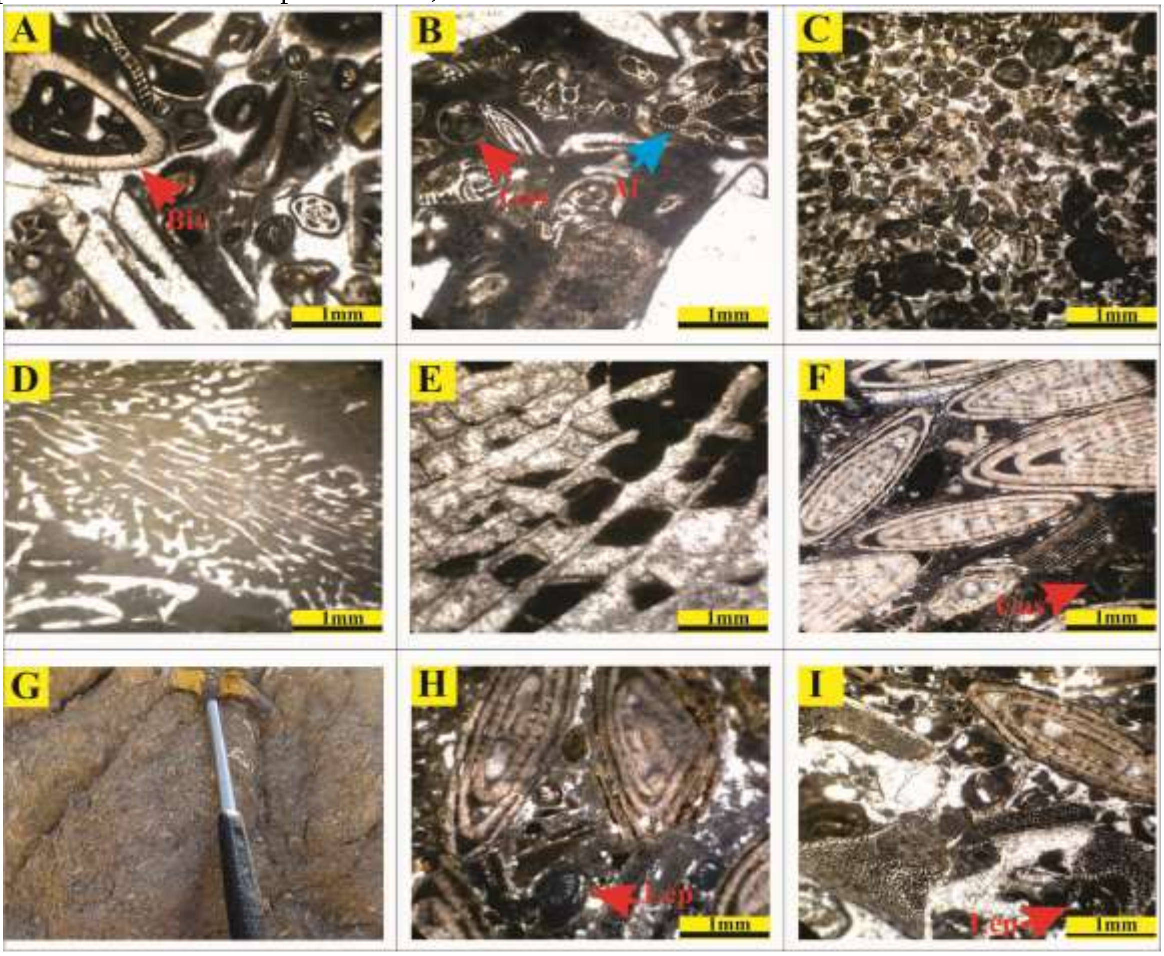

Figure (6): Microfacies (A) and (B) Bioclast grainstone/packstone (MF5): (C) Bioclast peloidal grainstone (MF6): (D) and (E) Coral boundstone (MF6): (F) and (G) nummulitidae bioclast wackestone–packstone(MF 8): (H) and (I) Bioclast, nummulitidae, lepidocyclinidae wackestone–packstone (MF9). Abbreviations:Gas:Gasropoda, Al: Algae, Lep: Lepidocyclinidae, Biv:Bivalves.

7. Sedimentary Facies Model:

On the basis of the distribution of the biota, textures, stratigraphy, lithofacies and vertical facies relationships, the Asmari Formation is interpreted to has been deposited on a carbonate ramp with a very gentle slope. The lack of any marginal reef development, absence of a major break in slope from shoreline into deeper water, widespread tidal flat deposits, and the presence of landward, high-energy grainstone facies are evidence that the sediments (Asmari Formation) were deposited on a carbonate ramp (Tucker et al., 1993; Flugel, 2010). Carbonate ramp environments are characterized by: (1) the inner ramp, between the upper shoreface and fair weather wave base, (2) the inner 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 (Burchette et al. 1992). Most carbonate sequences from the Asmari Formation were deposited in middle ramp environments in the Bandar-pol anticline.

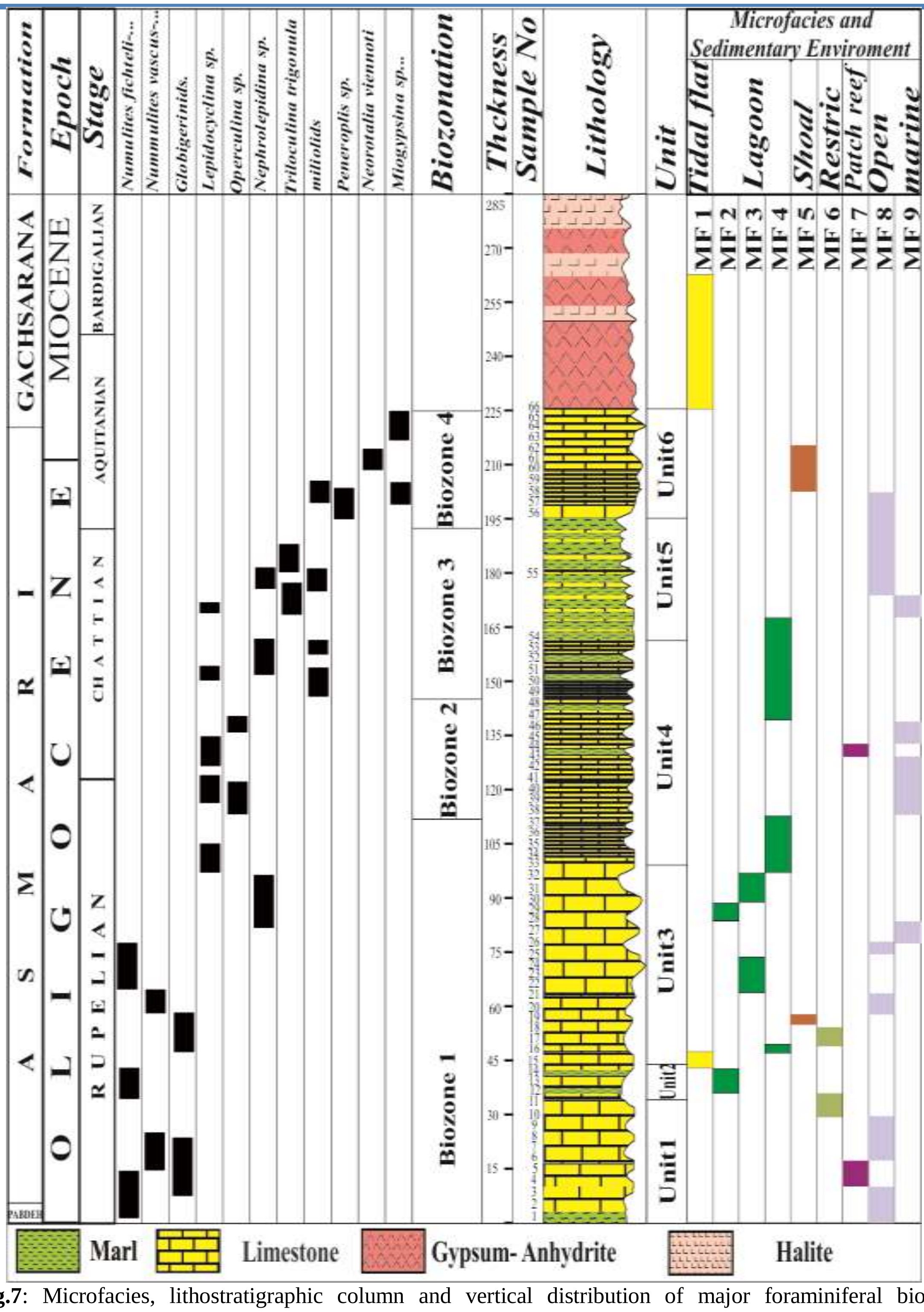

Fig.7: Microfacies, lithostratigraphic column and vertical distribution of major foraminiferal biozonation sequences of the Asmari Formation at Bandar pol section, Zagros.

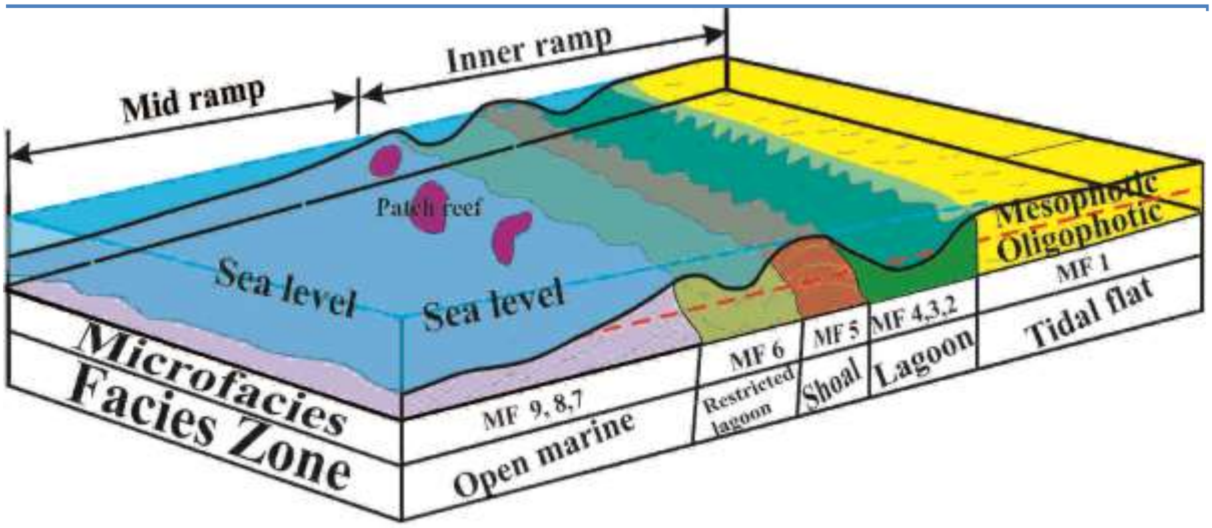

Fig.8: Depositional model for the ramp of the Asmari Formation in the study area.

Tidal flat facies (inner ramp): The tidal flat sediments are composed of boundestone with a fenestral fabric (MF1), (Fig. 5). This facies is thin and is recognized only at the bottom of the Asmari Formation in the Bandar-pol anticline. The main feature of this microfacies is the occurrence of Stromatolite fabrics. On the basis of the absence of fossils and presence of Stromatolite boundstone and mud matrix, it is considered that this microfacies formed under near surface, low-energy conditions, most likely in a tidal flat setting(Flugel, 2010).

Lagoonal facies (inner ramp):

This facies consists of bioclastic wackestone/packstone (MF2, 3, 4), (Fig. 3) in the study area. The presence of mud matrix in these three microfacies shows that, for the most part, deposition was in a low to moderate energy environment. Crinoids and benthic foraminifera are the main skeletal grains in these microfacies. The above conditions are suggested by the lack of a normal-marine biota and abundant of their skeletal components (benthic foraminifera such as miliolids). Lagoon facies types are highly variable but contain abundant imperforated tests of foraminifera (miliolids,). Towards the shoal, imperforated foraminifers and perforated foraminifera (nummulitids and lepidocyclinids) occur together.

Shoal and restricted facies (inner ramp): Shoal facies is characterized by bioclastic grainstone. Absence of sorted grains indicate high-energy conditions. The shoal facies was deposited in the platform margin sub-environment (Flugel, 2010), separating the open marine and lagoon environments. Bioclastic peloidal wackestone/packstone (MF6) occurred in the leeward part of the lagoon, while the other microfacies (MF2 and MF5) were deposited in the seaward part of the lagoon, representing deposition under high-energy conditions.

Open marine facies (middle ramp): The open marine facies includes MF8 and MF9. The open marine facies belt was developed at the seaward end of the middle ramp where the shoal facies graded to the open marine bioclastic wackestone (Fig. 7). The fine-grained character suggests deposition by low energy currents as suspension in shallow marine suite. The laminated nature implies a very low energy depositional environment. The benthic fossils (nummulitidae) suggest that this facies was formed as a deposit in shallow calm water, in an open marine environment, normally below the range of current activity. MF7 sequence of a piece not expand on the study area and deposited on the open marine. MF7 are included patch reef microfacies. Generally, it is believed that this facies was accumulated in quiet water conditions.

The Asmari Formation is interpreted to be a carbonate ramp with a very gentle slope (Fig. 8). The lack of any marginal reef development, absence of major break of slope from shoreline into deeper water, and the presence of landward high-energy grainstone facies is consistent with the Asmari Formation having been deposited on a carbonate ramp (Tucker et al., 1993). Therefore, sedimentological and biostratigraphy studies show that a carbonate ramp sedimentary model can be fully applied to these ancient carbonate deposits ((Tucker, 1985); (Tucker et al. 1990)).

8. **Conclusions:**

In the study area, the thickness of the Asmari Formation is 225 m. It is composed of thick to massive bedded limestone with intercalation of marl and alternation of limestone with marl. Based on the biostratigraphy of the Asmari Formation, age of this formation is Oligocene–Miocene (Oligocene (Rupelian) (Chattian), Early Miocene (Aquitanian)). Deposits of the Asmari Formation in the Bandar-pol area were deposited in a carbonate ramp similar to the Persian Gulf. Nine microfacies (Stromatolite boundstone, Peloid miliolids bioclast wackestone-packstone, miliolid intraclast-bioclast packstone, Bioclast, nummulitida, miliolids wackestone-packstone, Bioclast grainstone-packstone, Bioclast peloidal grainstone, coral Boundestone, nummulitidae bioclast wackestone–packstone, Bioclast, nummulitidae, lepidocyclinidae wackestone–packstone), characterizing a gradual shallowing and depositional environments correspond to inner and middle ramp, were identified. The microfacies studied were interpreted in terms of depositional environments as follows: MF1 (tidal flat), MF2-3-4- (lagoon), MF5 (shoal), MF6 (restricted), MF7 (patch reef), MF8-9(open marine) (Fig. 8).

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