Microfacies, Sequence stratigraphy, Facies analysis and Sedimentary environment of Neocomian in Kuh-e-Siah section (Arsenjan area, SW of Iran)

Masoud Abedpour[1,2], Massih Afghah[*2], Vahid Ahmadi[2], Mohammadsadegh Dehghanian[3]

1.Department of Geology, College Fars Science and Research Branch, Islamic Azad University, Fars, Iran.
2.Department of Geology, Shiraz Branch, Islamic Azad University, Shiraz, Iran.
3.Department of Geology, Bandar Abbas Branch, Islamic Azad University, Bandar Abbas, Iran.

Received 18 June 2017; accepted 19 December 2017

Abstract

In the present research Kuh-e Siah Section in the Northeast of Shiraz in the Interior Fars, was investigated to study microfacies, sequence stratigraphy, facies analysis and sedimentary environment of Fahliyan Formation. Generally, 345 meters of these sediments were studied by investigating 240 thin sections. In this study, the indicator microfacies were accurately identified which include Mudstone, Wackestone, Packstone and Grainstone. Besides, skeletal and non-skeletal grains of these microfacies are Intraclast, Bioclast, Exteraclast and Peloid. According to lithostratigraphic study, underneath limit of Fahliyan Formation with the Surmeh Formation and its upper contact with Gadvan Formation were in the gradual form (SB2) and included (TST-LST-Early HST-Late HST) system tracts. In general, there were two second-degree sequences in this section., According to the analysis of the sedimentary environment, the The lowermost of the Fahliyan Formaion is comprised of the Inner shelf deposit Which changes to Open marine sediments (with homoclinal type) And eventually terminates to outer shelf deposit. Based on the received micropaleontologic data, the age determination of the Fahliyan Formation Is assigned to Neocomian.
Keywords: *Microfacies, Sequence stratigraphy, Fahliyan Formation, Kuk-e- Siah, Iran*

1. Introduction

Neocomian and Barremian sediments in Persian Gulf and Zagros area have been determined as Fahliyan, Gadvan and Garau Formations. These sediments in Zagros area have latterally changed in bio and lithofacies characteristics, during the Neocomian age, confirming the tectonic and paleogeographical settings of the Zagros basin. Thus, the mentioned sediments with neritic shale, hemipelagic carbonate and pelagic facies in Fars, south of Dezful and southeast of Persian Gulf and with Fahliyan and Gadvan Formations in the north of Dezful embayment, Lorestan and northwest of Persian Gulf have been introduced as Garau, Fahliyan and Gadvan Formations, respectively.
Biostratigraphic study of the Jurassic-Cretaceous sequence reveals regression between the mentioned strata in different parts of Zagros as well as its better comparison with other regions in the Arabian Plate (Aghanabati 1998). Facies analysis of the Jurassic-Cretaceous succession, determining the relationship between the sequences by the sea-level fluctuation, tectonic setting, rate of sediment supply and age determination of the mentioned strata based on the bio and lithofacies would make it possible to present the sedimentary model and establish a conformity between the currently set sequences and other parts of the Iranian and Arabian Plates.

----
*Corresponding author.
E-mail address (es): massihafg2002@yahoo.com

Since studies on Fahliyan Formation have been focused on the oil-rich regions of southern Iran and there are few studies at this level on biostratigraphy, microfacies and sedimentary environment of Fahliyan Formation in the interior and coastal Fars (for e.g. Afghah 2006; Abyat et al. 2012; Abyat et al. 2016).

2. Methods and Materials

In order to study microfacies, sequence stratigraphy, facies analaysis, sedimentary Environment and biostratigraphy, Kuh-e Siah was selected which was one of stratigraphy section of Fahliyan Formation. Lower and upper lithostratigraphic limits were determined by detail field work, 240 samples were collected from selected section; then, thin sections were prepared from each sample for microscopic investigation. According to (Danelian et al. 1997; Dragstan 1982; Deloffre 1988; Canudo 2002; Afghah 2006; Jozas and Aubrecht 2008; Hossieni and Conrad 2008; Ivanova and Kołodziej 2010; Granier and Bucurm 2011; Turi et al. 2011; Abyat et al. 2012; Petrova et al. 2012; Krische et al. 2013; Lopez-Martinez et al. 2015; Abyat et al. 2016; Abedpuor 2017), the foraminifers and calcareous algae were determined. Investigation of foraminifer and calcareous algae stratigraphic distribution led us to established biozones and age deyermination of Fahliyan Formation in Kuh-e-Siah.

3. Geographical and Geological Setting

The studied section is located at southwest of Arsanjan (Fig 1a). The geographical coordinates (latitude and longitude) of this section are 29˚47'52"N and 53˚12'04"E, respectively (Fig 1b). Based on Alavi (2004), Zagros is divided into three major structural zones which are Simply-Folde, Imbricated and Metamorphic zones. Kuh-e-Siah stratigraphic section is located in Simply-Folded zone of the Zagros. Actually, structure of the Kuh-e-Siah is referred to an anticline with SW-NE trend similar other structures of the Zagros area (Berbarian and King 1981). It consists of well exposed of Jurassic though Cenomanian sequence (Surmeh, Fahliyan, Gadvan, Dariyan, Kazhdumi and Sarvak Formations) (Fig 2). Studied section is assigned to Interior Fars area by James and Wynd (1965). In this section, Fahliyan Formation is encompassed by Surmeh (mid to late Jurassic) and Gadvan Formations (Barremian) continously (Fig 3).

4. Description of the Lithostratigraphic units

Thickness of Fahliyan Formation is measured approximately 345m conformably overlies Surmeh Formation and is lithologically inseparable; further, it is underlied by the marls of Gadvan Formation and covers limestone of Surmeh Formation. Lithologically, this rock unit divided into five lithostratigraphic units as follows (Fig 4).

1) The initial 63m of this Rock unit is composed of cream thin-bedded to massivecolored dolomitic limestone with an interbed sandy limestone. This unit continuously lies over the dolomitic limestone of Surmeh Formation (Unit 1).

2) The second unit is described by 77m of dark gray thick-bedded to massive limestone with interbeds of sandy limestone and iron nodules.

3) The third unit is covered by 30m of dark gray medium-bedded limestone and, in the upper part, sandy limestone along with a small amount of iron nodules (Unit 3). It is better to add Unit 2 and 3 in this form: Alternation of dark gray medium to thick bedded with massive limestone and an interbed sandy limestone which is extended approximately 107m. This unit overlies the Unit 1.

4) The Unit 4 is determined by of gray thick to massive Limestone which is measured approximately 128m.

5) 47m of massive gray-colored limestone with iron nodules and it terminates to dark gray thick-bedded to massive limestone (Unit 5) which lies under the marly limestone of Gadvan Formation

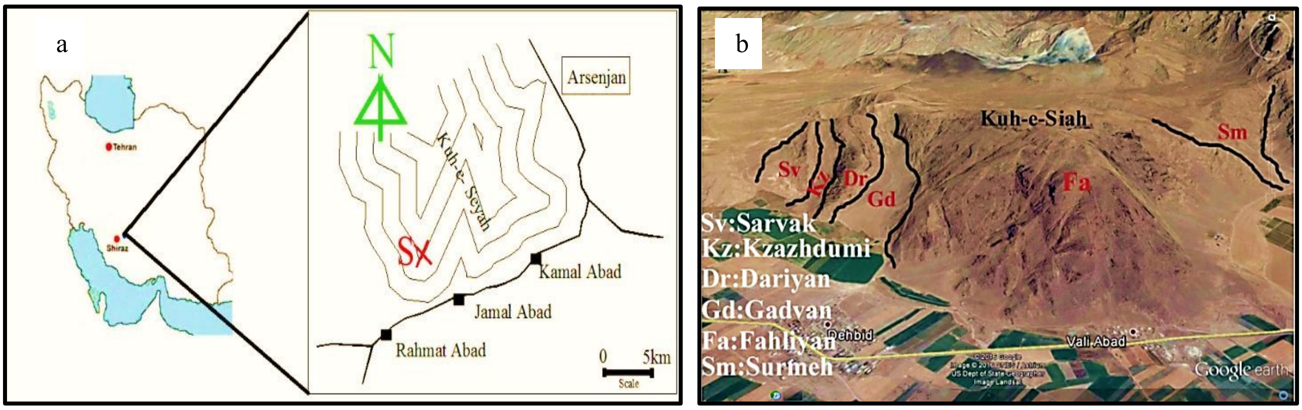

Fig 1. a) Geographical location of Fahliyan Formation in Kuh-e-Siah section b) Satellite image of Formations in the region (Google earth 2017)

Fig 2. Fahliyan Formation in the Kuk-e-Siah Section (the north side view)

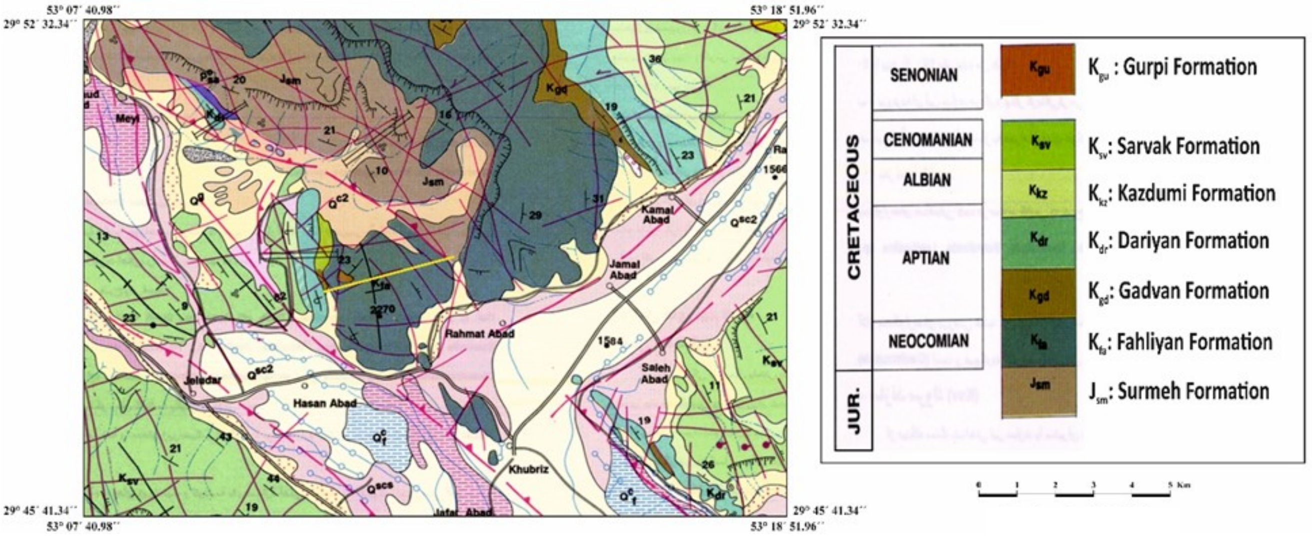

Fig 3. Geological map of Fahliyan Formation outcrop in stratigraphic section of Kuh-e-Siah (adopted from Arsanjan 1/100,000 map, Geological Survey and Mineral Exploration of Iran).

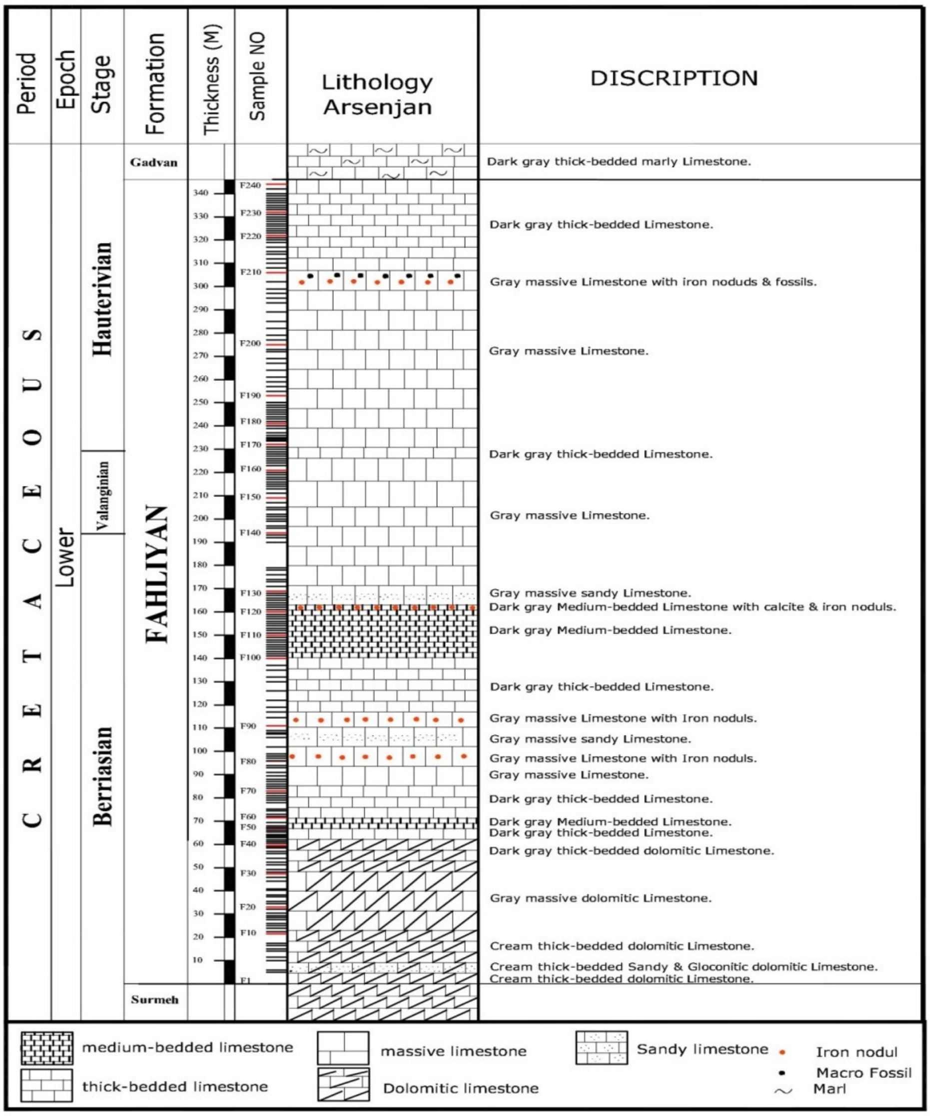

Fig 4. Stratigraphy column of Fahliyan Formation in Kuh-e-Siah section, Arsanjan.

5. Identify the Skeletal grains in microfacies and their environmental determination

5.1. Skeletal grains

Based on the type of microfacies, they are divided into several types, including foraminifera, lime algae, fragments of Bivalvia and Gastropod.

5.1.1. Foraminifera

Their extension in the stratigraphic section is statistically different and varied due to their paleo-ecological conditions, or changes in their environmental conditions. Some of the most important environmental factors that affect foraminifera include the temperature, amount of mineral content in the water, pressure, food, sedimentology properties of the meerschaum and, finally, the depth. In this section, various types of foraminifera with a porcelanose lime shell and a granular-type hyaline lime shell were found in microfacies (Khosrotehrani 2004). A quantitative percentage of foraminifera were between 8% and 45%. Generally, the observed foraminifera were similar to benthic forms of foraminifera.

Calpionella sp., *Pseudocyclammina* sp., *Pseudocyclammina lituus, Pseudocyclammina greigi, Trocholina alpina, Trocholina sagittaria, , Trocholina chouberti, Trocholina elongate, Trocholina arabica, Trocholina campanella, Trocholina altispira, Pseudochrysalidina (Dokhania) conica, Pseudochrysalidina (Dokania) arabica, Praechrysalidina infracretacea, Dictyoconus arabicus*, *Novalesia distorta, Nautiloculina* sp., *Nautiloculina oolithica, Nautiloculina* cf. *broennimanni, Siphovalvulina* sp., *Quinqueloculina* sp., *Mayncina* sp., *Glomspira* sp., *Ottemestella sudgeni, Pseudotextularia* sp., *Lenticulina* sp., *Choffatella decipiens, Pseudolitunella* sp., *Bekhmeia wetzeli, Lenticulina* sp., *Marsonella trouchus, Miliolidae.*

5.1.2. Foraminifera fragment

This group of skeletal grain in microfacies is the result of Wave base effect and their conveyance, which the crushing effects are observed on them. These foraminifera fragment sources from the existing foraminifera in the environment. Their crushing level depends on the foraminifera shell, the shellfish genus, the energy of the environment, as well as their geometric form, which is usually increasing in the front of the barrier and the subtidal (particularly, the boundary between subtidal and intertidal) (Khosrotehrani 2004). It should be noted that crushed foraminifera is usually seen along with residues of the healthy foraminifera or bigger shells fragments.

5.1.3. Gastropod and Bivalvia remains

These skeletal grains are are relatively distinguishable as a low rate skeletal grains in identified microfacies

5.1.4. Algal lithofacies

Generally, Diversified dasycladacea are distinduished in the Fahliyan Formation, Which are index of rate of sedimentation and paleoenvironment energy. Overall, algae represent an energetic environment with a high amount of oxygen and shallow sedimentary basin. The Paleobathymetery, of dasycladacea of algae are present in, is between 22 and 30 meters (the light zone). Dasucladacean habit are referred to muddy and sandy environments which are limited distribution in shallow water and lagoon. Geographical distribution of algal carbonates was documented before which was assigned to tropical waters with high temperature, low CO_2 content, and with saturated or over saturated $CaCO_3$ (Gollesstaneh 1965; Kalantari 1976). Considering the abundance of algal lithofacies, especially the dasycladacean in the Fahliyan Formation, it can be indicated that the sedimentation environment of this rock unit was the shallow water environment with muddy and sandy bed, low CO_2 pressure, and saturation or over saturation $CaCO_3$, relatively high salinity, and high temperature.

In this study among the identified calcareous algae, italic font is required refers to the *Gymnodiniaceae*, and the other of the identified genuses and species are determined as to the *Dasycladacean*. *Dasycladacean* and *Gymnodiniaceae* are found mainly in shallow water of inner ramps. *Gymnodiniaceae* are expanded to a greater depth than *Dasycladacea*. The shallow heaps and sub-restricted and restricted lagoon environments are characterized by the frequency of *Dasycladacea* algae. The *Salpingoporella* is commonly seen behind the riffs and open lagoons (Fluegel 2004).

The Paleo-ecological importance of green algae lime mudd was investigated in terms of tolerance of algae against temperature, sediments of bed, salinity, and water energy and it is believed that depth is important as the controlling factor of the other mentioned factors. Among the identified algae, other genuses and species are as follow:

Salpingoporella sp., Salpingoporella necomiensis, Salpingoporella meliatea, Salpingoporella annulata, Salpingoporella dinarica, Clypeina solkani, Clypeina gigantea, Actinoporlla podolica, Cylindroporella sp., Bacinella sp., Bacinella irregularis, Ottemestella sudgeni, Terqumella sp., Munieria baconica, Macroporella (Pianella) pygmaea, Macroporella pygmaea, Rajkaenella sp., Neomeris sp., Aciclaria sp., Thaumatoporella parvovesiculifera, Solenopora sp., Permocalculus sp., Permocalculus ampullacea, Permocalculus inopinatus, Solenoporella sp., *Lithophylum* sp.

5.2. Quantitative study of grains and paleogeographic interpretation

In the quantitative study of microfacies elements, frequency of skeletal and non-skeletal grains were investigated. The recognized non-skeletal grains is generally divided into three main categories: peloid, intraclast, exteraclast. The quantitative amounts of them in each of the stratigraphic sections and in the different parts differ from each other.

Actually the rate of the grains support the paleoenvironment condition it is necessary to note that, the Rate of exteraclast represents an increase in the environment energy. Also, there are several factors that along with a quantitative study determine the characteristics of the environment's formation time. These factors include the type of bioclast, the matrix characteristics, and even the peloid content, which will be discussed. Based on these statistical studies and the distribution of Allocem and destructive elements, each of the studied sections is introduced in terms of general characteristics.

5.2.1. Quantitative investigation of the microfacies in the studied section

The distribution curve of bioclast is associated with many changes. The minimum and maximum amount of bioclast are observed in the primary part of the section with 7% shelf and the middle part of the section with 60% inner shelf (lagoon), respectively. In general, the trend curve of bioclast percentage is convergent with intraclast curve. The percentage of intraclast is similar to that of bioclast, so that the maximum amount of them are 30% in the middle of section and the minimum amount of them in the primary parts are zero percent (0%). The highest level of Peloid at the end of the lower part is 15%, which is convergent with the bioclast curve. The percentage of exteraclast in the lower part starts at 8%. Next, this rate is reduced and the existence trend of these elements continues in the upper sections and the minimum amount of it is observed in the open marine sections (Fig 5).

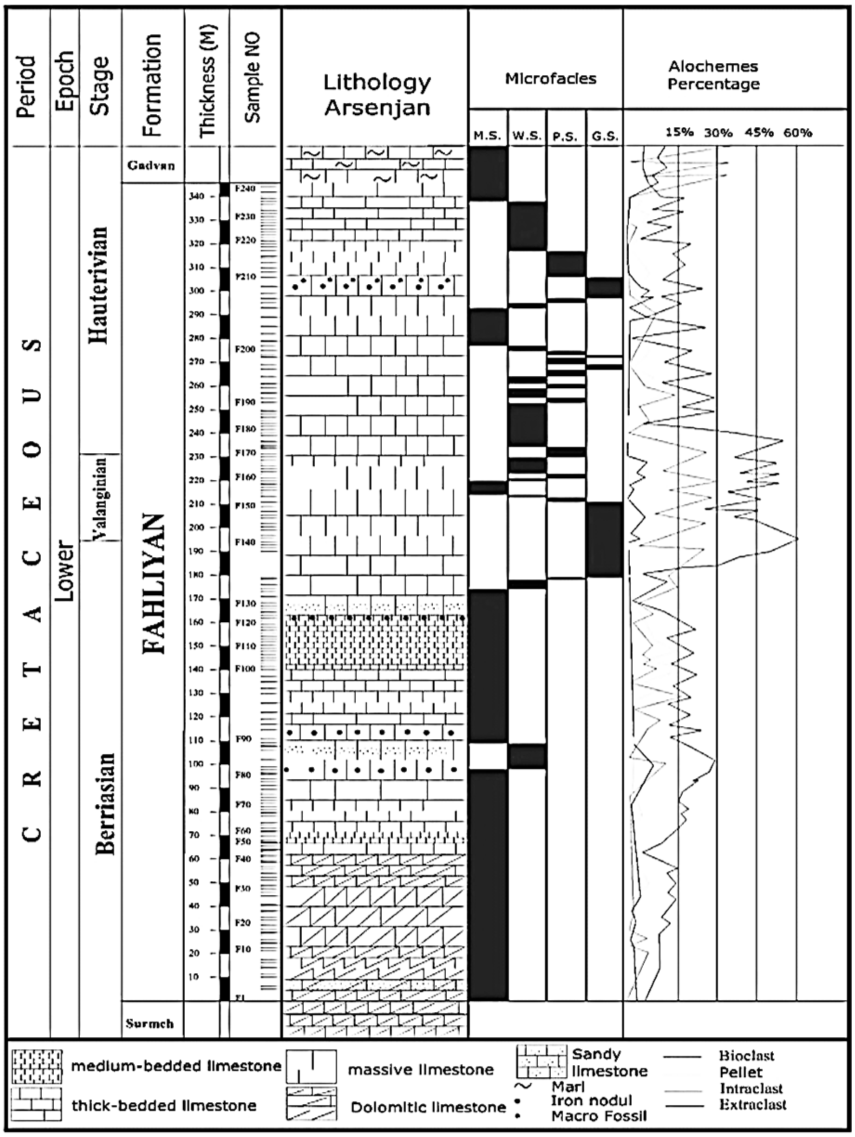

Fig 5. Shows the distribution of stratigraphy, carbonate microfacies and its elements in the Kuh-e-Siah Section

6. Descriptions and differentiation of detected microfacies

Microscopic studies and determination of the percentage and type of their grains and matrix led to the identification of 17 carbonate facies in Fahliyan Formation, which is located in the Coastal Plain, Inner shelf, Middle shelf, and Outer shelf. The stages of these studies are as follows:

- Determine the stone contexture in the each of the studied segment, based on Dunham (1962) classification
- Classification of facies and presentation of sedimentary model by Wilson (1975) and Carozzi (1980) method.

-laboratory studies rely on Carozzi (1980), Lasemi and Carozzi (1981) and Fluegel (2004) and considering Walter's law (Middleton 1973) and comparison with modern sedimentary environments (Fig 6). The description of the microfacies of this Formation, which is the basis of the stratigraphy sequence, from the shallow depth to the deep, respectively includes:

6.1. Coastal plain

a. Dolomitic sub-lithofacies

This facies includes only dolomite and does not have any biological effects. This sub-lithofacies is recognized in the lower part of the Fahlian Formation and represents the outer part of the supratidal. This facies is comparable to RMF 26 and SMF25 (Wilson 1975; Fluegel 2004). This facies is also identified by Abyat (2012) (Plate 1. Fig 1).

b. Dolomadstone microfacies

This facies includes dolomudstone with moulds of evaporating minerals that refer to the upper part of the tidal flat. This facies is comparable to RMF 22 and SMF20 (Wilson 1975; Fluegel 2004). This facies is also identified by Maleki and Lasemi (2011) and Abyat (2012) (Plate 1. Fig 2).

c. Stromatolite boundstone microfacies

Stromatolite luminescences that often subjected to dissolution and dolomitization are the main builder of this microfacies. Silt and quartz particles are also visible in this facies. Observation of Fenestral porosity with mentioned elements indicates that this facies is formed in the lower part of the tidal flat. This facies is comparable to RMF 22 and SMF20 (Wilson 1975; Fluegel 2004). This facies is also identified by Jamalian et al. (2010), Maleki and Lasemi (2011) and Abyat (2012) (Plate 1. Fig 3).

6.2. Inner shelf

a. Algal peloidal wackestone microfacies

The peloid with 25 to 30% frequency and bioclast with 10 to 15% are the builders of this facies. Peloids are slightly shaped and rounded. This indicates that this facies is formed at a lower depth than the previous facies. Non-skeletal grains include ooid and intraclast, which are observed with less percentage in this facies. Identified bioclasts include green algae, such as *Salpingoporella*, Gastropoda, and Foraminifera such as *Pseudocyclammina*, *Trocholina*, *Textularia* and *Miliolida* (Folk 1962). This facies is comparable to RMF 20 and SMF16 (Wilson 1975; Fluegel 2004). This facies is also identified by Adabi et al. (2010), Jamalian et al. (2010), Maleki and Lasemi (2011)and Abyat et al. (2012) (Plate 1. Fig 4).

b. Algal peloidal mudstone microfacies:

Peloid is the major Non-skeletal grain of this facies. The distinguished bioclasts include green algae, gastropod, and echinoderm debris, *Bacinella* and *lenticulina*. Accordingly, this facies is formed in the low-energy part of the inner shelf facing the tidal flat as well as the presence of Peloid and inner shelf bioclasts. This facies is comparable to RMF 20 and SMF16 (Wilson 1975; Fluegel 2004). This facies is also identified by Abyat (2012) (Plate 1. Fig 5).

c. *Bacinella* wackestone microfacies:

The *Bacinella irregularis* alga is the main organic remain component of this facies (about 20-25%). The Matrix is majorly comprised of calcareous mud. In addition to *Bacinella*, and other bioclast (e.g. green algae *Stromatoporoid*, green algae, Gastropod, residues of Echinoderm and sponge spicule are also recognized. Foraminifera are also other skeletal grain of this facies, which the most important of these are *Pseudocyclammina*, *Trocholina Miliolida*. Peloid and intraclast are also found in low frequency in this facies. The mentioned facies is equivalent to SMF18 and RMF17 microfacies (Wilson 1975; Fluegel 2004). This facies is also identified by Jamalian et al. (2010) and Abyat (2012) (Plate 1. Fig 6).

d. Bioclast *Salpingoporella* packstone microfacies:

In addition to Gastropod, Sponge spicules, bivalve remains and Echinoderm, algae such as *Bacinella irregularis*, Foraminifera e.g. *Dokhnia*, *Pseudocyclammina*, and *Trocholina* are also observed. Matrix is generally made of calcareous mud (micrite). This facies is comparable to RMF20 and SMF18 (Wilson 1975; Fluegel 2004). This facies is also identified by Adabi et al. (2010), Maleki and Lasemi (2011) and Abyat (2012) (Plate 1. Fig 7).

e. *Trocholina* wackestone microfacies

Trocholinids are well distributed skeletal grain of this facies which are preserved by sparry calcite. Moreover *Pseudocyclammina lituus*, *Praechrysalidina infracretacea*, *Siphovalvulina* sp. and *Miliolida* are the other distinguishable foraminifers of this facies. Similar other facies, matrix is cinsisted of calcareous mud. Other bioclasts are Gastropods, Sponge spicules, residues of Bivalvia, Echinoderm and also green algae such as *Salpingoporella, Bacinella*. This facies is comparable to RMF20 and SMF18 (Wilson 1975; Fluegel 2004). This facies is also identified by Jamalian et al. (2010) and Abyat (2012) (Plate 1. Fig 8).

6.3. Middle shelf

a. Bioclast peloidal grainstone microfacies

The dominant non-skeletal grain in this microfacies is peloid with 20% to 30% frequency, and bioclast (10% to 20%) is also observed significantly. Foraminifera, green algae and Echinoderm fragments are the most important microfossils of this facies. This facies is comparable to RMF26 and SMF16 (Wilson 1975; Fluegel 2004). This facies is also identified by Adabi et al. (2010), Maleki and Lasemi (2011) and Abyat (2012) (Plate 2. Fig 1).

b. Ooidal peloidal grainstone microfacies

This facies is described by a high frequency of Peloid and ooid (25-30%). Similar to the previous facies, benthic foraminifera such as *Dokhnia*, *Pseudocyclammina lituus* and calcareous algae, such as *Salpingoporella*, *Bacinella*, *Clypeina*, were also identified in this facies. Aggregate and intraclast were also found in low rate in this facies. This facies is comparable to RMF29 and SMF16 (Wilson 1975; Fluegel 2004). This facies is also identified by Jamalian et al. (2010) and Abyat (2012) (Plate 2. Fig 2).

c. *Salpingporella* aggregate ooidal grainstone microfacies

The dominant non-skeletal grain of this facies is ooid (15-25%) co-occur with Aggregate (5-15%) similar to previous facies. Aggregate consists of dasycladaceae algae such as *Salpingoporella*, and foraminifers such as *Trocholina* which associates with ooid. Mentioned ooids have micritic structure. Peloid and oncoid are also found in this facies to a low frequency. This facies is comparable to SMF15-M (M is an abbreviation of Micritie ooid) and RMF29 (Wilson 1975; Fluegel 2004). In (Folk 1962) classification, this facies is called the sparite. This facies is also identified by Adabi et al. (2010) and Abyat (2012) (Plate 2. Fig 3).

d. Intraclast ooidal grainstone microfacies

The major non skeletal grain of this facies consists of micritized ooid (25-30%), radial structure ooids are welldominant. Intraclast and sometimes oncoid recognized as other non-skeletal grain of this facies that are observed with a lower rate. Like the previous facies, particles have well sorting and roundness. Matrix is made of sparry calcite, which indicates the high energy of the environment in the middle part of the middle shelf. Skeletal grains are generally consisted of foraminifera (e.g. *Pseudocyclammina lituus* and *Dokhania* sp.), Echinoderm fragments and bivalve remains. Recognition of diversified calcareous algaesuch as *Salpingoporella*, *Bacinella* and *Clypeina* indicates shallow water paleoenvironment (Afghah 2016; Afghah 2006). This facies is comparable to SMF15-C (C is an abbreviation of Concentric ooid) and RMF29 (Wilson 1975; Fluegel 2004). This facies is also identified by Adabi et al. (2010) and Abyat (2012) (Plate 2. Fig 4).

e. Peloidal intraclast grainstone microfacies

The non-skeletal grains are consisted of intraclast (about 20-30%) and peloid (about 15-20%) which are well rounded and sorted as major textural frame. Sparry calcite is distinguished as matrix. Due to the high energy of the environment, these particles have well roundness and sorting. Along with these two allocems, microfossils such as foraminifera and algae are observed. Among the foraminifera one can name *Dokhnia*, *Pseudocylamina*, *Prachrysalidina infraccretacea*, *Trocholina* and among the algae can be mentioned *Salpingoporella*, *Bacinella*. In addition to the ooid, aggregate and Gastropod are observed with lower percentages in this facies. This facies is comparable to SMF14 and RMF26 (Wilson 1975; Fluegel 2004). This facies is also identified by Jamalian et al. (2010) and Abyat (2012) (Plate 2. Fig 5).

f. Coral boundstone microfacies

Coral and calcareous algae (*Bacinella*) are the main organic remains and along with them stromatoporida and some foraminifera are also observed. Actually, they indicate shallow water with high light and high energy, so this facies is formed in a part of the middle shelf that is higher than the impact surface of normal waves. This facies is comparable to SMF7 and RMF12 (Wilson 1975; Fluegel 2004). This facies is also identified by Abyat (2012) (Plate 2. Fig 6).

6.4. Outer shelf

a. Orbitolina bioclast wackestone microfacies

The main skeletal grain of this facies is discoid *Orbitolinids* and along with them, sponge spicules, Echinoderm spine, Bivalvia and other foraminifera (e.g. *Pseudocylammina*, *Trocholina*, and *Chofatella* are recognized. Calcareous mud is known as matrix. This facies is comparable to SMF9 and RMF8 (Wilson 1975; Fluegel 2004). This facies is also identified by Jahani and et al. (2009) and Abyat (2012) (Plate 2. Fig 7).

b. Bioclast packstone microfacies

This facies is majorly consisted of skeletal grains (e.g. benthic foraminifera, Sponge spicules, Echinoderm spine, Bivalvia). Non skeletal grain co-occur with calcareous algae with low frequency. The benthic foraminifera, Sponge spicules, Echinoderm spine, Bivalvia and, less amount of alga and Peloid. This facies belongs to the low-outer shelf areas. This facies is comparable to SMF3 and RMF2 (Wilson 1975; Fluegel 2004). This facies is also identified by Jahani et al. (2009) and Abyat (2012) (Plate 2. Fig 8).

c. Sponge spicule echinoids wackestone microfacies

This faciec contains Skeletal grains 35-40% which consists of Sponge spicules Echinoderm and Bivalvia spine, small gastropods, foraminifera such as *Dokhnia*, *Pseudocylammina*, *Trocholina*, *Orbitolina*, *Chofatella* (35-40%), calcareous algae and radiolarian ares rarely recogmized. The micritic matrix and the types of the grains indicate that the microfacies are deposited in the deep outer shelf and below the surface zone. This facies is comparable to SMF3 and RMF2 (Wilson 1975; Fluegel 2004). This facies is also identified by Jahani et al. (2009) and Abyat (2012) (Fig 7).

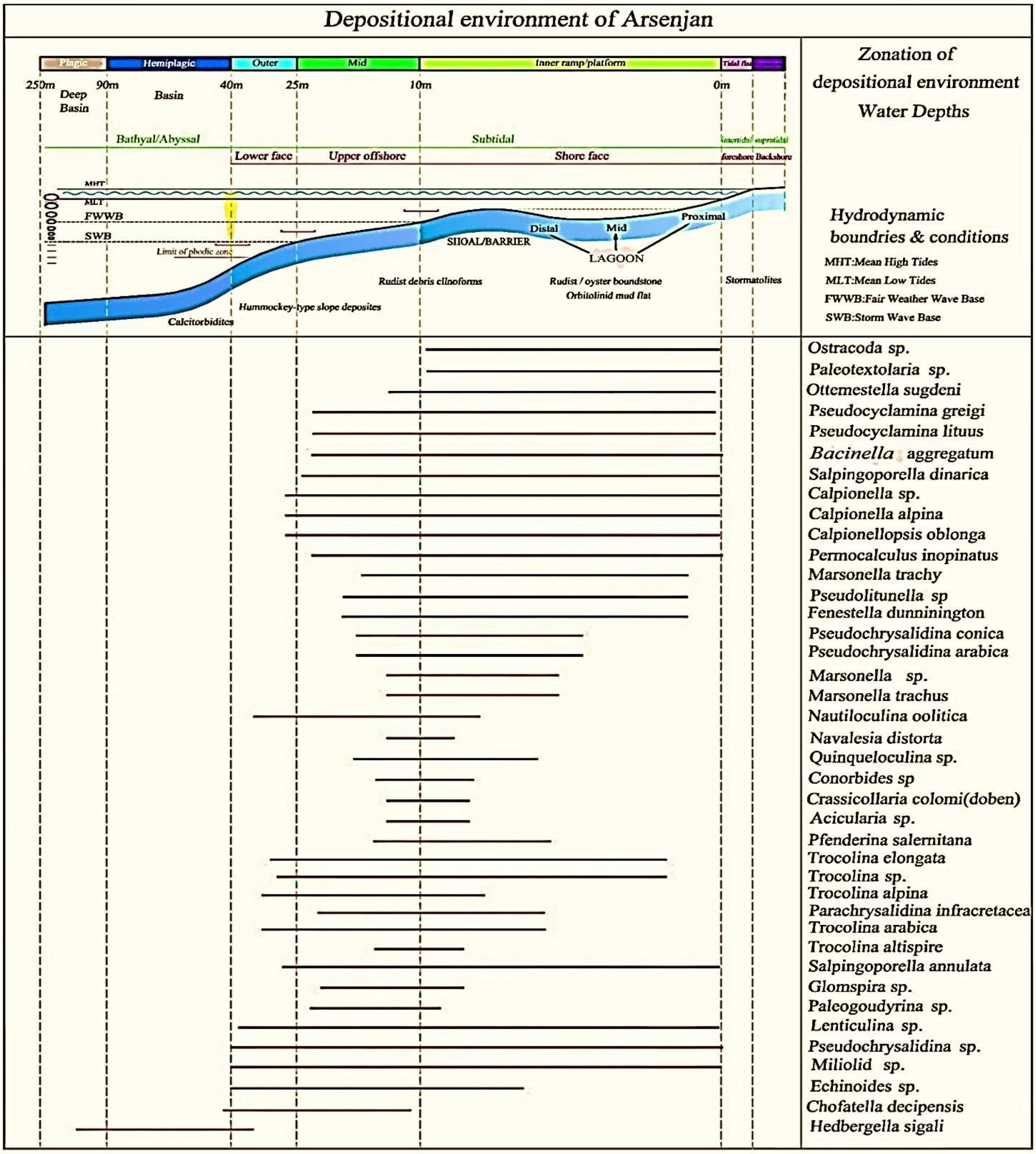

Fig 6. Distribution of foraminifera and non-foraminifera in reconstructed sedimentary environments of Fahliyan Formation in the Arsanjan sections (Adapted from the joint project of the French Petroleum Institute and the National Iranian Oil Company, 2006)

7. Sequence stratigraphy

According to sequence stratigraphy, two complete second-order sediment sequences and a third- order progress were identified (Baum and Vail 1988; Emery and Myers 2005). The age of Sequence 1 is lower Berriasian. The lower lithostratigraphic contact of the Fahliyan Formation with Surmeh Formation is determined gradually (SB2) (Sarg 2001), which indicates a regression which is synchronous with global discontinuities without emerging from the water not occurred at this boundary. The upper boundary is also the second type (SB2) with sequence number 2. Based on received micropaleontological data the age of Sequence 2 is referred to upper Berriasian-lower Hauterivian. The lower boundary of sequence number 2 with sequence 1 and its upper bound with the start of a progression are both incremental (SB2) (Fig 8).

(plate1)

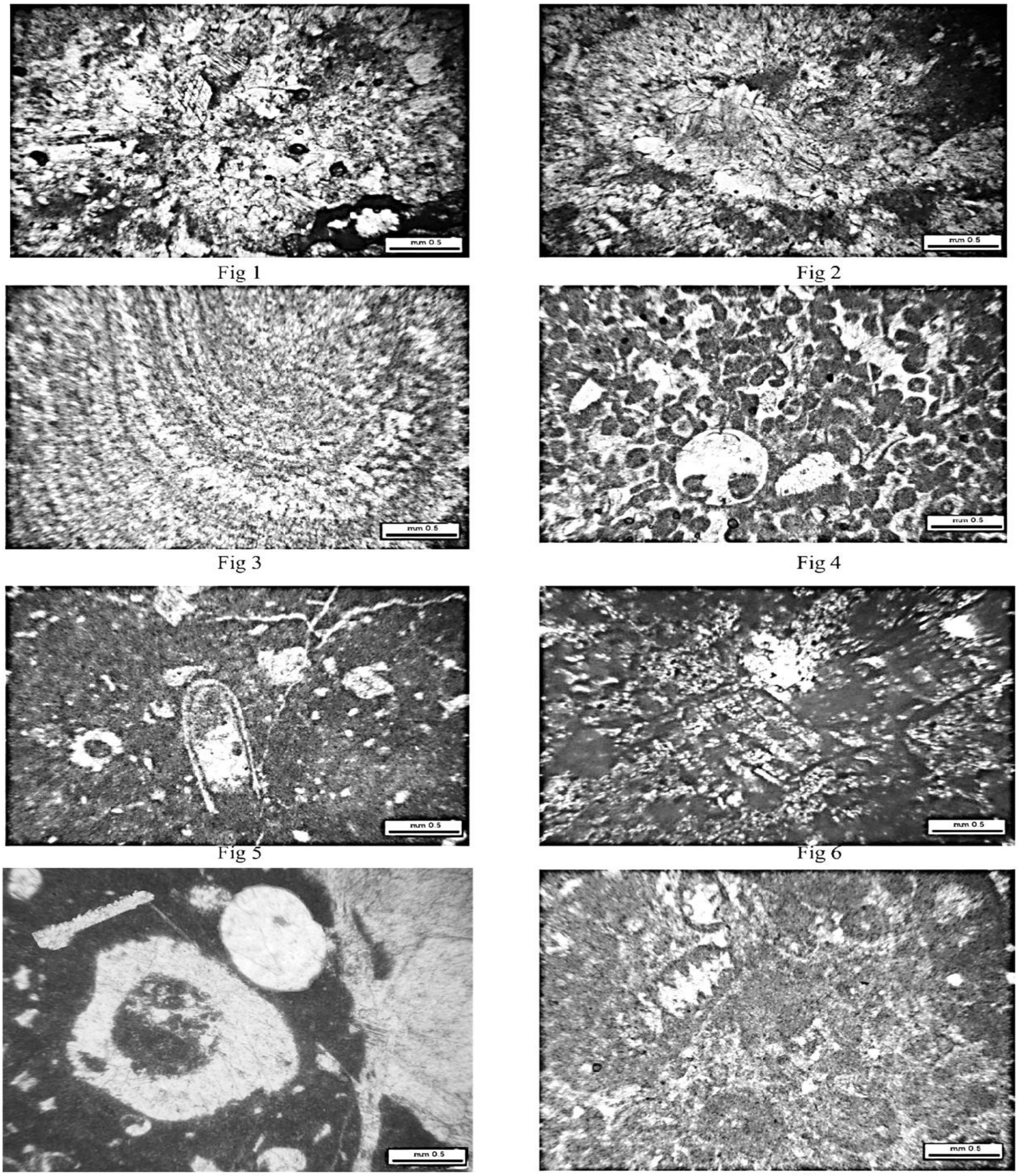

Plate1: Fig 1) Dolomite microfacies, Fig 2) Dolomadstone microfacies, Fig 3)Stromatolite boundstone microfacies, Fig 4) Algal peloidal wackestone microfacies, Fig 5) Algal peloidal mudstone microfacies, Fig 6) *Bacinella* wackestone microfacies, Fig 7) Bioclast *Salpingoporella* packstone microfacies, Fig 8)Wackestone microfacies *Trocholin*

(Plate2)

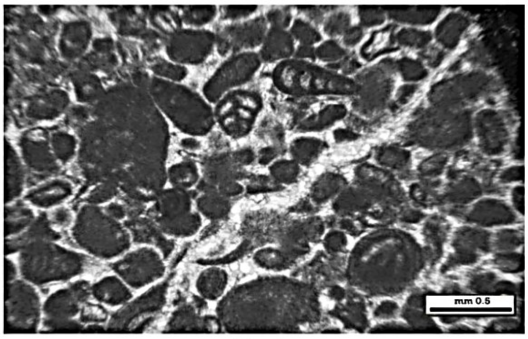

Fig 1

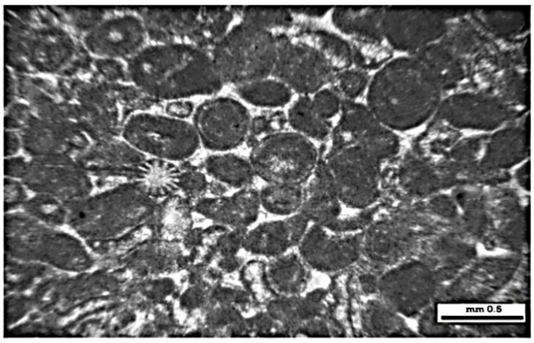

Fig 2

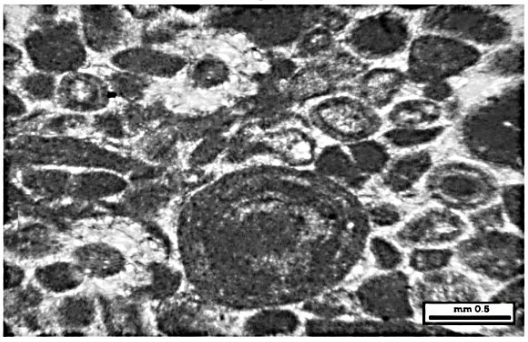

Fig 3

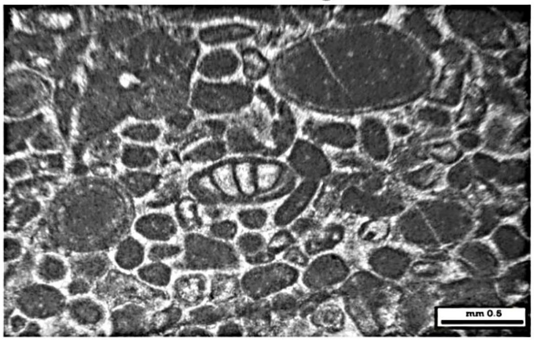

Fig 4

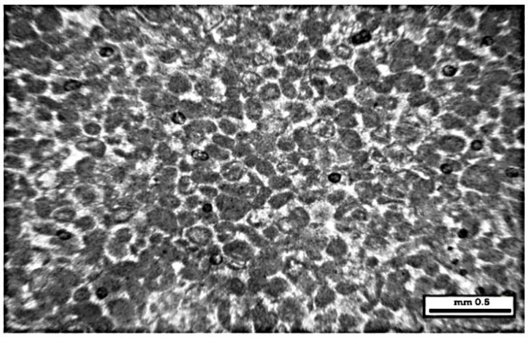

Fig 5

Fig 6

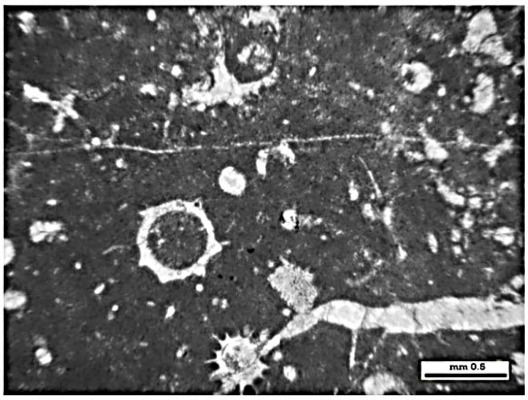

Fig 7

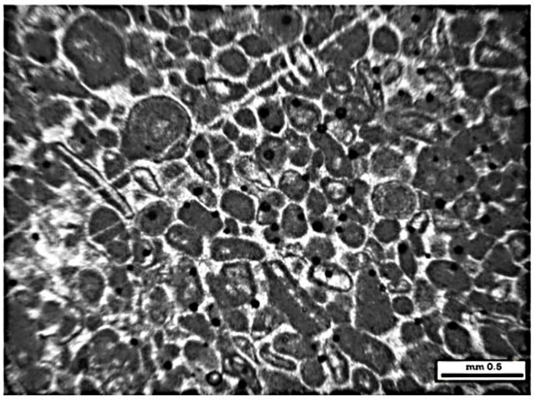

Fig 8

Plate2: Fig1) Bioclast peloidal grainstone microfacies, Fig 2) Ooidal peloidal grainstone microfacies, Fig 3) *Salpingporella annulata* ooidal grainstone microfacies, Fig 4) Intraclast ooidal grainstone microfacies, Fig 5) Peloidal intraclast grainstone microfacies, Fig 6) Coral boundstone microfacies, Fig 7) Sponge spicule echinoids wackestone microfacies, Fig 8) Bioclast packstone microfacies

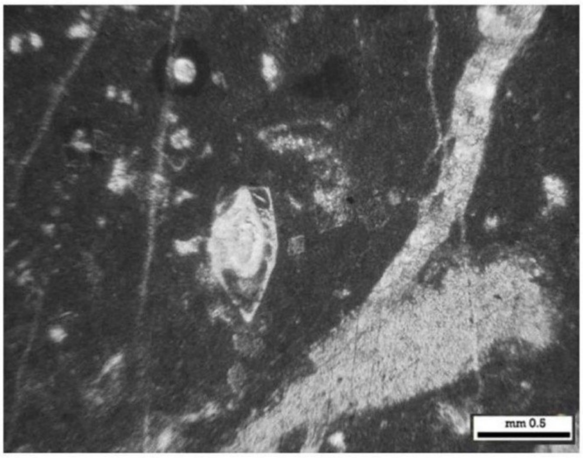

Fig 7: *Trocholina* bioclast wackestone microfacies

Sequence 1: indicates a significant regression at this limit, which is associated with dolomitic facies of the Surmeh Formation at the uppermost of Jurassic, and the base of Fahlian Formation. There is a Tintinid facies which assigned to upper Surmeh and lower Fahliyan Formations, the lower border of this sequence is SB2, which is concurrent with the late Kimmeridgian movement and regional regression. The upper boundary of sequence 2 is SB2-type sea-level lowstand. This sequence is extended approximately 117 meters. In terms of lithostratigraphic, this sequence includes the lower part of the Fahliyan Formation. Regards to stratigraphic position of *Calpionella alpina* zone, the age of this sequence is Berriasian. This sequence begins with the coastal dolomite facies and continues with the inner shelf limestone facies. Then, the continuation facies of the inner shelf are placed on these facies. The microfacies in this sequence indicate the most progression of the basin or mfs at 118 meters.

Sequence 2: The second sequence starts at 118 meters and observes up to 308 meters and its solidity is 190 meters and includes the major part of Fahliyan Formation in this section. The upper and lower boundaries starts with sequence 1 and the beginning of following progress is SB2 type. Due to the Stratigraphic position in the Biozone range of the upper part of the *Calpionella alpina* zone and the entire zone of *Pseudochrysalidina conica* zone and *Pseudocyclamina lituus Trocholina* zone, this sequence, belongs to the upper Berriasian to the lower Hauterivian. In terms of lithostratigraphic, this sequence is located in the middle to upper of *Pseudocyclamina*. This sequence begins with the inner shelf facies, and the mid and outer shelf facies covers it. This sequence consists of an inner shelf TIS progressive facies with 53 m with age of upper Berriasian and Early HST facies with 60m thickness and age of Valanginian, Late HST facies with 77m thickness and age of lower Hauterivian and mfs is marked in 172m.

The beginning of the transgression: The effect of the mention transgressive movement is distinguishable in upper lithostratigraphic part of Fahliyan and lowermost of Gadvan Formations Stratigraphic position of *Trocholina*, *Pseudocyclammina lituus* assemblage zone confirms Hauterivian-lower Barremian age of the mention transgression. The lower boundary of the transgression facies is marked by 37 meters of sediments which is bounded by SB2 type of outer shelf paleoenvironment. The continuation of transgression towards open marine is determined (Fig 9).

8. Discussion

The studies have led to the identification of five sedimentary environments for the Fahliyan Formation sediments. In this study, considering the diversity of facies, vertical and lateral classification and models provided by Wilson (1975) and Fluegel (2004), can be propose shelf environment for these sediments using the joint project model of the French Petroleum Institute and the National Iranian Oil Company (2006), as well as (Van Buchem et al. 2010) in the Zagros Basin.

The well distributedooidal and peloidal facies, confirms the sedimentation of these sequences in the carbonate shelf environment. Similar data facies has been reported before by (Adabi et al. 2010) in the type section and Gachsaran oil field, (Lasemi and Feizi 2007) in Izeh zone, (Lasemi et al. 2003) from Binak and Khoviz.

Lack of Bioclasts in tidal flat indicate the sedimentation in the coastal environment (Amodio 2006). This condition can be generalized in identified Dolomudstone microfacies and Dolomite microfacies. The bioclasts are reduced from the inner shelf (Stromatolite boundstone microfacies facies) toward the coast (Dolomite microfacies facies).

In addition, in this regard, the amount of dolomitization is increased so that Dolomite morphology facies is completely dolomite. The boundstone represents the intertidal to supertidal environment (Palma et al. 2007a, b). In general, this facies indicates a low lowstand sea-level, as common facies which is formed in the lower part of the Fahliyan Formation at the early Neocomian. The presence of evaporite moulds, stromatolite and fenestral texture, and birds eyeis a sign of the coastal flat (Playa and Gimeno 2006; Adabi et al. 2010; Maleki and Lasemi 2011). The presence of micritic faciesthe inner shelf indicates a lack of enough energy to move the micritic limestone (Fluegel 2004).

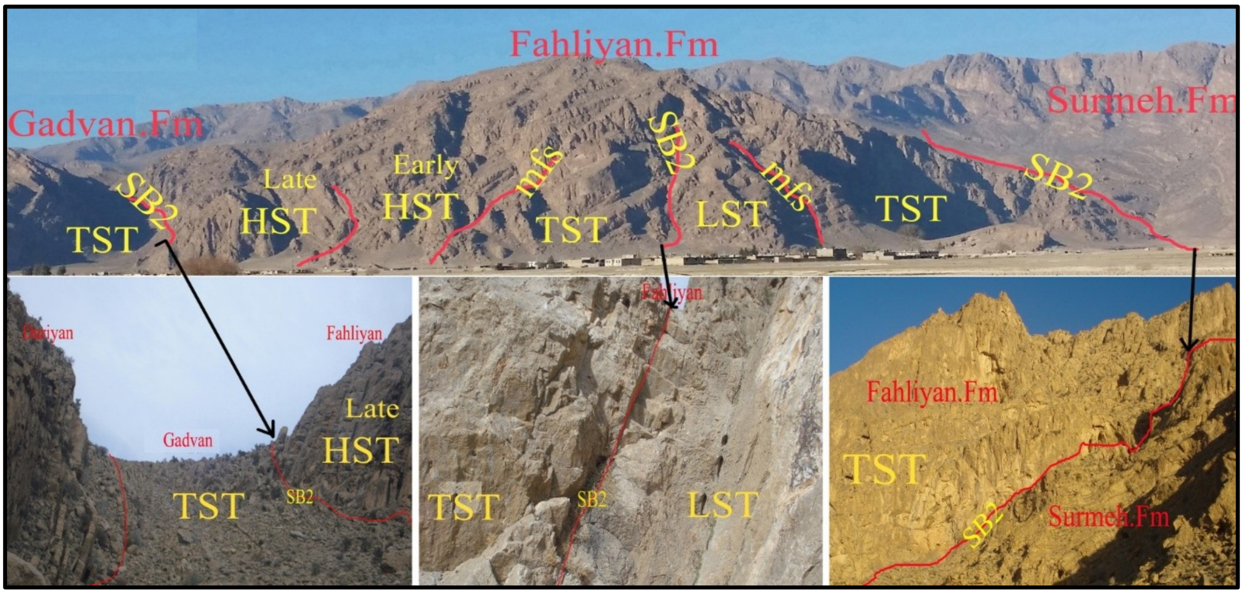

Fig 8. Field aspects of the Fahliyan Formation at Kuh-e-Siah (Arsenjan area). The lower and upper Surmeh, Gadvan Tongue and sequence stratigraphic subdivisions of the formation are indicated on the log.

Other inner shelf features include Aragonite foraminifer shell (like *Trocholina*) which are filled with sparry calcite (Booler and Tucker 2002). The presence of green algae, along with the benthic foraminifera in a micritic facies, represents low energy in the parts of the inner shelf (Bachmann and Hirsch 2006). Calcareous algae are important organic constituent in the Cretaceous-Zagros limestone (a joint project of the French Petroleum Institute and the National Iranian Oil Company (2006); (Gollesstaneh 1965; Mosadegh and Parvaneh Nejad Shirazi 2009; Adabi et al. 2010). Actually, the presence of Bioclast Salpingoporella packstone facies or *Bacinella* wackestone or Algal peloidal wackestone and Algal peloidal packstoneis similar the mentioned previous micropaleontologic data base. Appearance of calcareous algae represent warm seas with normal salinity and a depth about 3 to 5 meters (Reading 1996). Sponge spicules are documented both in the outer shelf and in the inner shelf (Wilson 1975; Wright and Tucker 1991). These bioclasts may be shifted from the outer shelf to the inner shelf. Sponge spicules are found in a low energy zone with normal salinity and a depth about 10 meters in aggregation with algae (Wells 1965). The variety and frequency of foraminifera in these environments are reduced (Amodio 2006). However, the Occurrence of benthic foraminifera, *Bacinella*, algae fragments, gastropods and intraclast indicate the inner shelf environment near the middle shelf. Peloid is co-occur with different bioclasts, Non-skeletal grain of the inner shelf, which is observed in this environment (Bachmann and Hirsch 2006; Adabi et al. 2010). The peloid facies of the studied section (algal peloidal mudstone and algal peloidal wackestone) are recognized in the mentioned environment. Previous works (e.g. a joint project of the French Petroleum Institute and the National Iranian Oil Company, (2006), (Purser and Evans 1973; Lasemi and Carozzi 1981; Bucur and Săsăran 2005) Support the sedimentation take place in shallow water wave base zone. Coral boundstone faciesIs recorded as lateral expanded catbonates which is assigned to mid shelf belong to the middle shelf, has a very small lateral extension and solidity. This microfacies is formed in a shallow marine environment far from the beach or in the front part of the middle shelf. The grain supported texture, superficial ooid, well sorted and roundness represent mid shelf. It deposited in a low energy environment, indicating their displacement from a low-energy environment to high-energy environments through dam damping channels (Tucker and Wright 1990). In the outer shelfIs marked by association of the Sponge spicules, the Echinoderm and intraclasts with a higher percentage, the Radiolaria, the foraminifera (such as *Dokania*) with a lower percentage, the tintinoid with a much smaller percentage, along with.

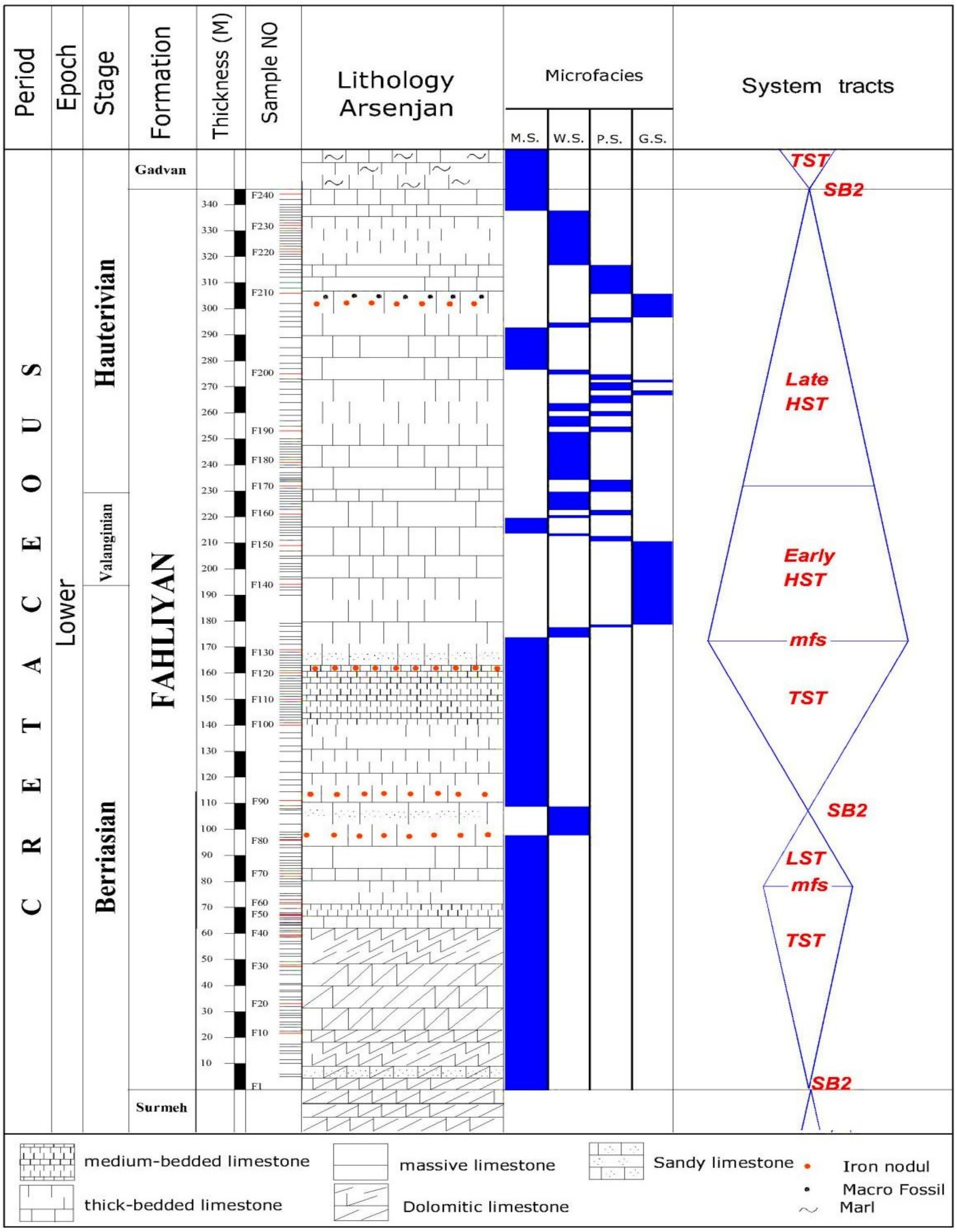

Fig 9. Sequence Stratigraphy column of Fahliyan Formation in Kuh-e-Siah Section, Arsanjan.

the elements fragment, and the easy transportation ability of calcareous algae (Fluegel 2004) can transfer these particles from lagoon environments to open marine environments (a joint project of the French Petroleum Institute and the National Iranian Oil Company (2006), (Van Buchem et al. 2010; Schlagintweit and Bover 2012). According to well aboundant paleoecologic system and global scale of tectonic effect, four tectono-sedimentary episodes are described.

8.1. Episod I (early Berriasian – late Barremian)

Carbonate platform of the Fahliyan Formation (Sediment Model 2) is prograded in Fars region and eventually converted to siliciclastic deposits of Fahliyan and Gadvan Formations (Sediment Model 3). Sedimentation in this episod is controlled by sea level changes, sedimentation rates and subsidence rates. According to the project of the French Petroleum Institute (IFP) and the National Iranian Oil Company (2006), three facies types can be considered for this section:

Type 1: Algal-foraminiferal shelf wedge carbonate platform (Berriasian)
Type 2: Oolitic-algal, carbonate platform (Valanginian, Hauterivian)
Type 3: Mixed siliciclastic- carbonate platform (Hauterivian, Barremian)

8.2. Sediment Analysis of Fahliyan Formation in the studied section

Primary sedimentation of shallow carbonate of Fahliyan Formation lowermost lithostratigraphic limit is described by dolostone of tidal flat paleoenvironment which covers the upper part of Surmeh Tintinid facies. Then the lagoon facies are changed change to barrier environment. Finally, at the end of the outershelf is determined by with the Echinoderm, spicule facies, the wackestone of the shallow carbonate of Fahliyan Formation with a maximum depth of 40 meters in this section gradually turns into limestone and the Gadvan Formation marls. Micropaleontologic and paleoecologic data confirm age range of Valanginian-Hauterivian and mainly are in the lagoon environment. The coastline prograds from a tidal flat with a gentle and gradual slope towards the open marine (Fig 10).

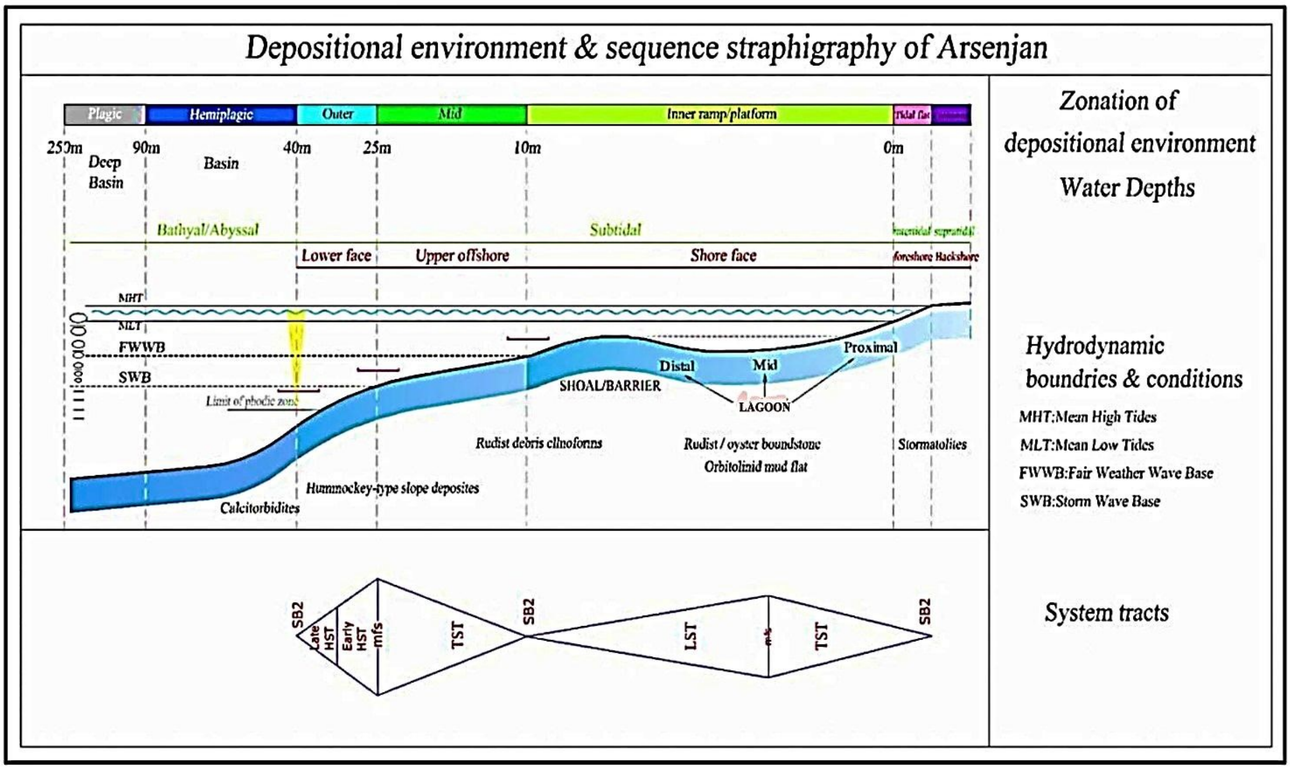

Fig 10. Depositional environment and Sequence straphigraphy of Arsenjan

9. Conclusions

Reconstruction of sedimentary environment of the Fahliyan (Neocomian) requires facies analysis of well exposed stratigraphic sections and study of tectonic effect (global and local scales) during sedimentation. Moreover paleoecologic of Fahliyan Formation supports the basin analysis of Necomian succession in Zagros area. However, role of Zagros Main Thrust is as significant as sedimentation control in Zagros area. Therefore interpretation of the sequence stratigraphy requires both the detail field study and microscopic investigation of well exposed Jurassic (Surmeh Formation) and lower Cretaceous strata (Fahliyan and Gadvan Formations). Faunal assemblage is a good key to sea-level fluctuation which may causes by many factors such as basement fault activities and global sea-level change.

References

Abedpour M (2017) Biostratigraphy, Facies analysis and Sedimentary Environment Correlation of Fahliyan Formation in Interior and Coastal Fars area (SW of Iran). PhD thesis, Islamic Azad University (Shiraz Branch), 312p (in Persian) .

Abyat A, Baghbani D, Afghah M, Afsari S, Ghadimvand KN (2016) Neocomian-Barremian Foraminifers and Algae from Coastal Fars (South Iran), *Arabian Journal of Geosciences* 9:262.

Abyat A, Baghbani D, Afghah M, Afsari S, Ghadimvand KN (2016) Neocomian-Barremian Foraminifers and Algae from Coastal Fars (South Iran), *Arabian Journal of Geosciences* 9:262.

Abyat A, Baghbani D, Afghah M, Ghadimvand KN, Feghi A (2012) Microbiostratigraphy and Lithostratigraphy of Fahliyan and Gadvan Formations in Kuh-e-Surmeh (Zagros Basin, Southwest Iran), *Advances in Environmental Biology* 6:3078-3086.

Abyat A (2012) Lithostratigraphy, Biostratigraphy and Sequence stratigraphy of the Neocomian–Barremian sediments along a transect from Golshan well in Persian Gulf to Kuh-e Gadvan in northern parts of Zagros. Ph.D Thesis on Geology, Islamic Azad University Science and Research Branch, 350 p.

Adabi MH, Salehi MA, Ghobishavi A (2010) Depositional environment and geochemistry of Lower Cretaceous carbonates (Fahliyan Formation), south-west of Iran, *Journal of Asian Earth Sciences* 39:148−160.

Afghah M, Abtahian A, Saberi A (2016) Foraminiferal Biostratigraphy of (Early Cretaceous, Hauterivian-Barremian) Sediments of the Zagros Basin (SW of Iran), *Journal of African Earth Sciences* 121:42-55.

Afghah M (2006) Microbiostratigraphy of Fahliyan Formation in Kuh-e-Gadavan and Ab Siah, *Journal Of Sciences (Islamic Azad University)* 61:89-107.

Aghanabati A (1998) Jurassic Stratigraphy of Iran. Geological Survey of Iran,

Alavi M (2004) Regional Stratigraphy of the Zagros Fold-Thrust Belt of Iran and Its Pro-foreland Evolution, *American Journal of Science* 304:1-20.

Amodio S (2006) Foraminifera diversity changes and paleoenvironmental analysis: the Lower Cretaceous shallow-water carbonates of San Lorenzello, Campanian Apennines, southern Italy, *Facies* 52:53-67.

Bachmann M, Hirsch F (2006) Lower Cretaceous Carbonate Platform of the Eastern Levant (Galilee and Golan Heights): Stratigraphy and Second-Order Sea Level Change, *Cretaceous Research* 27:487-512.

Baum GR, Vail PR (1988) Sequence stratigraphic concepts applied to Paleogene outcrops, Gulf and Atlantic basins. *The Society of Economic Paleontologists and Mineralogists* 1988:309-27.

Berberian M, King GCP (1981) Towards the paleogeography and tectonic evolution of Iran. *Canadian Journal of Earth Sciences* 18:210–265.

Booler J, Tucker, ME (2002) Distribution and Geometry of Facies and Early Diagenesis: The Key to Accommodation Space Variation and Sequence Stratigraphy: Upper Cretaceous Congost Carbonate Platform, Spanish Pyrenees. *Sedimentary Geology* 146: 225-247.

Bucur I, Săsăran E (2005) Relationship between algae and environment: an Early Cretaceous case study, Trasc ˘au Mountains, Romania, *Facies* 51:274–286.

Canudo JI (2002) Chapter 13: Tintínidos. In: Molina, E., Ed., Eustoquio MOLINA, Unive- sidad de Zaragoza, Espana, 265-280.

Carozzi AV (1980) Carbonate Rock Depositional Modle: A Microfacies Approach. Prentice-Hall, Upper Saddle River, New Jersey.

Danelian T, DeWever P, Azema J (1997) Palaeoceanographic Significance of New and Revised Palaeontological Datings for the Onset of Vigla Limestone Sedimentation in the Ionian Zone of Greece, *Geological Magazine*134:869-872.

Deloffre R (1988) Nouvelle Taxonomie des Algues Dasycladales (New Taxonomy of Dasycladale Algae), *Bull. Centres Rech. Explor.-Prod. Elf-Aquitaine* 12:165-217.

Dragstan O (1982) Lower Cretaceous Marine Algae and Calpionellida from Canada (San Pedro)-Asturisa Province (Spain), *Journal of Iberian Geology* 8:127-143.

Dunham RJ (1962) Classification of carbonate rock according to depositions texture, in ham, W.E. (ed): Classification of carbonate rock, Sympo Amer.Assoc.Petrol.Geol.Memoir.108-121.

Emery D, Myers K (2005) Sequence Stratigraphy, Oxford, Blackwells Science.

Fluegel E (2004) Microfacies of Carbonate Rock, Springer Verlag Berlin, 976p.

Folk RL (1962) Spectral subdivision of limestone types, in Ham, W. E. (ed.), Classification of carbonate Rocks-A Symposium, *American Association of Petroleum Geologists Memoir* 1:62-84.

Gollesstaneh A (1965) Micropalaeontological study of the Upper Jurassic and Lower Cretaceous of Southern Iran. Unpubl. PhD. Thesis, University College, London, 629p.

Granier B, Bucurm I (2011) Stratigraphic Ranges of Some Tithonian-Berriasian Benthic Foraminifers and Dasycladales. Re-Evaluation of Their Use in Identifying This Stage Boundary in Carbonate Platform Settings, Boletin del Instituto de Fisiografia y Geologia 79-81.

Hosseini SA, Conrad MA (2008) Calcareous Algae, Foraminifera and Sequence Stratigraphy of the Fahliyan Formation at Kuh-e-Surmeh Zagros Basin, SW of Iran, *Geologia Croatica* 61:215-237.

Ivanova D, Kołodziej B (2010) Late Jurassic-Early Cretaceous Foraminifera from Š tramberk-Type Limestones, Polish Outer Carpathians, *Studia UBB Geologia* 55:3-31.

Jahani D, Peyman F, Jamali AM (2009) Study of Microfacies and Paleoenvironment of Gadvan Formation in Kuzekuh, Northeast Norabad, *Journal of Sediment and Sedimentray Rock* 5:1-12.

Jamalian M, Adabi MA, Moussavi MH, Sadeghi A, Baghbani D, Ariyafar B (2010) Facies characteristic and paleoenvironmental reconstruction of the Fahliyan Formation, Lower Cretaceous, in the Kuh-e Siah area, Zagros Basin, southern Iran, *Facies* 57(1):101-122.

James G, Wynd J (1965) Stratigraphic nomenclature of Iranian oil consortium agreement area, *American Association of Petroleum Geologists* 49:2182-2245.

Jozas Š, Aubrecht R (2008) Barremian-Aptian Erosion of the Kysuca-Pieniny Trough Margin (Pieniny Klippen Belt, Western Carpathians), *Geologica Carpathica* 59:103-116.

Kalantari A (1976) Microbiostratigraphy of sarvestan Area Southwestern, Iran, *National Iranian Oil Company Publication* 5:1-52.

Khosrotehrani K (2004) Carbonate Facies, Islamic Azad University Science and Research Branch.

Krische O, Bujtor L, Gawlick H (2013) Calpionellid and Ammonite Biostratigraphy of Uppermost Jurassic to Lower Cretaceous Sedimentary Rocks from the Leube Quarry (Northern Calcareous Alps, Salzburg, Austria), *Austrian Journal of Earth Sciences* 106:26-45.

Lasemi Y, Carozzi AV (1981) Carbonate Microfacies and Depositional Environments of the Kinkaid Formation (Upper Mossissippian) of the Illinois Basian, USA, VLL. Congreso Geologico Argentino, San Luis, Aclas II 357-384.

Lasemi Y, Feyzi M (2007) Platform and offplatform facies of Fahliyan Formation: evidence for intrashelf basin in southwest of Iran, In: 25th Symposium of Geology, Geological Survey of Iran, pp.84-85 (in Persian).

Lasemi Y, Mohammadkhani H, Khazaei M, Kavoosi MA (2003) Depositional environment and sequence stratigraphy of the Fahliyan Formation in Rag-e-Sefid, Binak and Khaviz Oil Fields, south Dezful Embayment, proceedings of the 7th Annual Meeting of the Geological Society of Iran 323-327.

Lopez-Martinez R, Barragan R, Rehakova D (2015) Calpionellid Biostratigraphy across the Jurassic/Cretaceous Boundary in San José de Iturbide, Nuevo León, Northeastern Mexico, *Geological Quarterly* 59:581-592.

Maleki S, Lasemi L (2011) Sedimentary Environment Sequence Stratigraphy of the Fahliyan Formation in Assaluyeh (Bidkhon) and Khartang Sections, Southwest Iran, *Journal of Basic and Applied Scientific Research* 1(12):2641-2647.

Middleton GV (1973) Johannes Walther's Law of the Correlation of Facies, *Geological Society of America* 84:979-988.

Mosadegh H, Parvaneh Nejad Shirazi M (2009) Algal Biozonation of Fahliyan Formation (Neocomian) in the Zagros Basin, Iran, *GRA* 11:2009-8507.

Palma JHN, Graves AR, Burgess PJ, van der Werf W, Herzog F (2007a) Integrating environmental and economic performance to assess modem silvoarable agroforestry in Europe, *Ecological Economics* 63:759-767.

Palma, JHN, Graves AR, Bunce RGH, Burgess PJ, de Filippi R, Keesman KJ, van Keulen H, Liagre F, Mayus M, Moreno G, Reisner Y, Herzog F (2007b) Modelling environmental Benefits of silvoarable agroforestry in Europe, *Agriculture, Ecosystems & Environment* 119:320-334.

Petrova S, Rabrenović D, Lakova I, Koleva-Rekalova E, Ivanova D, Metodiev L, Malešević N (2012) Biostratigraphy and Microfacies of the Pelagic Carbonates across the Jurassic/Cretaceous Boundary in Eastern Serbia (Stara Planina—Poreč Zone), *Geologica Balcanica* 41:53-76.

Playa E, Gimeno D (2006) Evaporite deposition and coeval volcanism in the Fortuna Basin (Neogene, Murcia, Spain), *Sedimentary Geology* 188:205–218.

Purser RH, Evans G (1973) Regional sedimentation n along the Trucial Coast, SE Persian Gulf", In: The Persian Gulf. Holocene carbonate sedimentation and diagenesis in shallow epicontinental sea, (Ed.: R.H. Purser), Springer-Verlag, Berlin: 211-231.

Reading HG (1996) Sedimentary Environments and Facies (3rd Ed.), Blackwell Scientific.

Sarg JF (1988) Carbonate sequence stratigraphy. *SEPM Special Publications* 42: 155-188.

Schlagintweit F, Bover-Arnal T (2012) The morphological adaptation of Lithocodium aggregatum Elliott (calcareous green alga) to cryptic microhabitats (Lower Aptian, Spain): an example of phenotypic plasticity, *Facies* 58(1):37–55.

Tucker ME, Wright VP (1990) Carbonate sedimentology: Blackwell, Oxford, 482p.

Turi V, Săsăran E, Bucur I (2011) New Data on the Upper Jurassic-Lower Cretaceous Limestones from Bihor Mountains: Case Study of Garda Seacă-Hodobana Region, Romania, *Studia UBB Geologia* 56:11-27.

Van buchem FSP, Gerdes KD, Esteban M (2010) Mesozoic and Cenozoic carbonate systems of the Mediterranean and the Middle East: stratigraphic and diagenetic reference models–an introduction, Geological Society, London Special Publications 329:1-7.

Wells AJ (1965) Lithofacies and Geological History of Khamy Group in Southwest Iran, National Iranian Oil Company. Report No. 1082, Tehran (unpublished).

Wilson JL (1975) Carbonate Facies in Geological History, Springer-Verlag, Berlin.

Wright VP, Tucker ME (1991) Calcretes: An introduction. In: Calcretes, V.P. Wright and M.E. Tucker (Eds), Blackwell, Oxford, 352p.