Journal of Himalayan Earth Sciences Volume 57, No. 1, 2024 pp. 23-39

Biostratigraphy and microfacies analysis of the Mid Cretaceous sequence in south Zagros basin

Asiyeh Arampour [1], Massih Afghah [1*], and Mahnaz Parvaneh Nejad Shirazi [2]
[1] *Department of Geology, Shiraz branch, Islamic Azad University, Shiraz, Fars, Iran*
[2] *Department of Geology, Shiraz branch, Islamic Azad University, Shiraz, Fars, Iran*
[3] *Department of Geology, Payame Noor University of Shiraz, Fars, Iran*
**Corresponding author: massihafg2002@yahoo.com*
Submitted date: 27/04/2020 Accepted date: 29/11/2023 Published online: 31/03/2024

Abstract

The marine deposits of middle Cretaceous Arabian continental margin are assigned to the Kazhdumi and Sarvak formations and best exposed in the south Zagros Basin (SW Iran). However, detailed studies related to the sedimentary environments, biostratigraphy and microfacies distribution of the middle Cretaceous sequence in south Zagros basin are still scarce. This study presents detailed biostratigraphic and microfacies analysis of the Kazhdumi and Sarvak formations on two sections in the northeast Interior Fars zone to reconstruct the sedimentary evolution of Middle Cretaceous Arabian continental margin. The Kazhdumi Formation is conformably worn by Sarvak Formation. The biozones were encountered in the studied areas and the following seven assemblage zones have been defined. Stratigraphic distribution of identified foraminifers supports Albian to late Cenomanian age of Kazhdumi and Sarvak Formations at the study area. The recognized eleven microfacies in Kazhdumi and Sarvak formations are clustered into lagoon, tidal flat, barrier and open marine sedimentary environments. A carbonate shelf and shallow ramp is suggested for Sarvak and Kazhdumi Formation respectively. The transgressive and highstand deposits reveal a predominance of deep and shallow subtidle facies respectively.

Keywords: Biostratigraphy; Facies, Middle Cretaceous; Interior Fars; Zagros Iran.

1. Introduction

During Eocene (35 Ma), rifting of Arabian litho-sphere beneath the Iranian Plate forms the Zagros fold and thrust belt is formed (Opera et al., 2013). This collision results into mountains of Alpine-Himalayan belt (extending 1800 km from Iran to Turkey) (Alavi, 2004) (Figs. 1a, b, and c). Alavi (2004) divided the Zagros structural zone into three zones such as: Metamorphic, Simply-Folded, and Imbricated zones. Structural zones are sub-categorized based on regional trend (NS and EW) of the faulrs (Berberian, 1995). Various studies of Kazhdumi and Sarvk Formations have been done by different authors (e.g., Kalantari (1976); Ghavidel-Syooki (2003); Vincent et al. (2010); Mohammadi et al. (2011); Shirazi et al. (2011); Arzaghi et al. (2012); Shirazi and Andalibi. (2013); Afghah et al. (2014); Afghah and Dookh (2014); and Afghah and Fadaei (2015)). In this paper an effort is made to illustrate and identify various kind of microfacies and biozonation using observations of petrographic and field study. Also identification of the environment of deposition of the Sarvak and Kazhdumi formations has been made (Interior Fars) (Figs. 1a and c). The strata of Sarvak and Kazhdumi formations in the region were studied in two separated stratigraphic sections. The range is located near the high Zagros zone and in the northern portion of the interior Fars. The studied area is located 18 and 110 km southeast of Saadat Shahr and Shiraz, respectively (Fig 1b).

Previous studies of Wynd (1965) and James and Wynd (1965) of the middle Cretaceous Kazhdumi and Sarvak Formation in the oil rich regions of the Zagros have mainly focused on lithostratigraphy and biostratigraphy. However, detailed microfacies and sedimentological research is still scarce in this area. The transgression in the early Aptian period led to burial of the Dariyan Formation (Shuaiba Formation of the Afro-Arabian plate) (Fig. 1d). At the late Aptian period, Khami limestone (group) of Kazhdumi Formation is deposited. An unconformity is resulted in the

Early-Albian low-amplitude regression (at the bottom of the Darian Formation), which was revealed by exposed carbonates platform of shallow water and the emergence platform of the Arabian-Nubian (Ziegler, 2001). In the Lorestan depression, sedimentation in the Kazhdami intra-shelf basin has continued without a break (Vincent et al., 2010). In different regions of the Zagros, Kazhdumi Formation has a limited extension but the Sarvak Formation is widely spread. Mid Jurassic rock unit of the Surmeh Formation. The oldest lithostratigraphic unit in the studied area are mid-Jurassic Surmeh Formation representing thick bedded limestone and dolomitic limestone (Fig. 2).

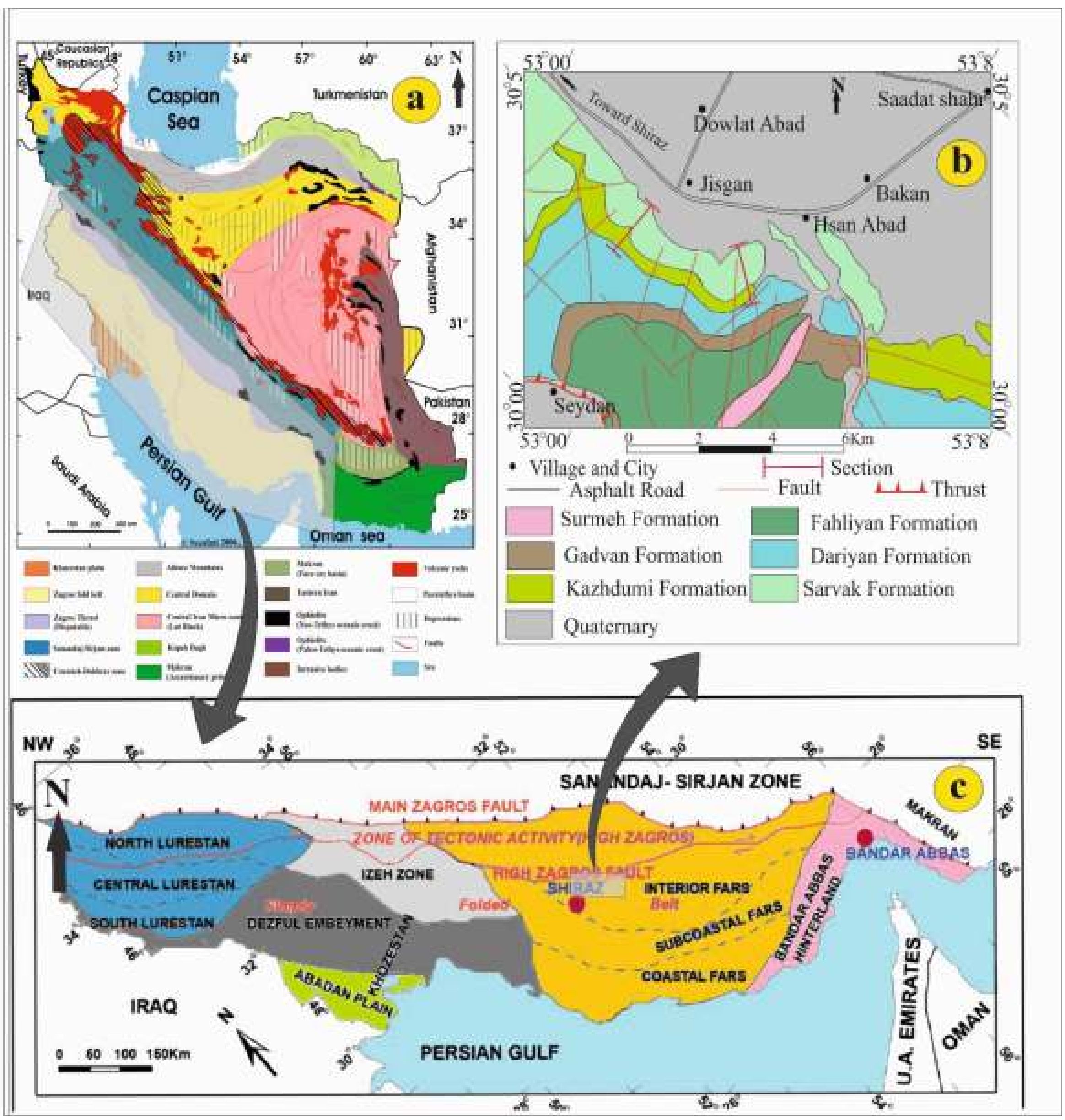

Fig. 1. a) Modified structural map of Iran (from Aghanabati, 2004), b) The locations of measured sections in northeast Fars interior zone and map of the study areas that show zoomed geology, and c) Tectonic of the Zagros area (Motiei, 1995).

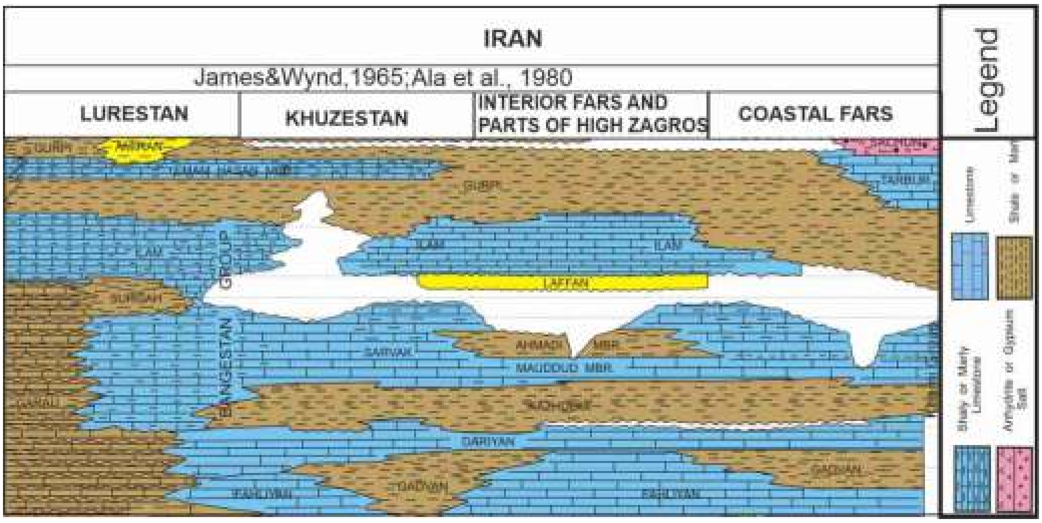

Fig. 2. Correlation chart of Cretaceous stratigraphic rock units of Iran (Lurestan, Khuzestan, Fars).

2. Methods and materials

The lithology of the studied sections has been described by fieldwork and includes the type of bed, color, lithology, thickness and changes in lateral rock facies. 141 thin sections (40 samples of Kozhdami Formation and 80 samples of Sarvk Formation) were prepared thin sections were studied under the polarizing microscope for biostratigraphic and facies analysis, commonly used in National Iranian Oil Company (NIOC). Identification of the investigated foraminifers, algae and other microfossils are according to Bolli Miles and Orr (1959); Wynd (1965); Gasiński (1983); Caron (1985); Coccioni and Premoli Silva (1994); Verga and Premoli Silva (2002, 2003 and 2005); Neagu (2005); Coccioni et al. (2007); and Premoli Silva et al. (2009). For the description of microfacies, Dunham (1962) and Embry and Klovan (1971) classification is used. The definition of Microfacies data was based on the characteristics of facies, that include grain depositional texture, composition, energy index classification, sorting, size and fossil content in grains. Abundance of non-skeletal grains, foraminifera, echinoderms, green algae, gastropoda, and bivalves (e.g., intraclasts and peloids) were also studied.

3. Results and discussion

3.1 Lithostratigraphy

The Kazhdumi Formation cover the Dariyan Formation with a transitional relation and underlies the Sarvak Formation in both studied sections (Figs. 3a and b). The lower lithostratigraphic contact is marked by an oxidized zone (Fig. 3c). The measured thickness of Kazhdumi Formation is 61 meters, and generally includes alternative limestone and argillaceous limestone and marly limestone with intercalation of thin bedded chert units. The investigated units contain bioclasts of different sets of fragment fossil and foraminifera (associated with gastropods, echinoderm, bivalves remain). Also, calcareous algae are recognized in this Formation. Sarvak Formation is composed light to grey, thin to thick-bedded limestone, which is comprised of foraminifera, bivalves and other fossil fragments. In section Sarvak Formation thickness is measured 72 meters. Gurpi Formation in section obviously overlies the Sarvak Formation (Figs. 3a, b, and c). In the following, the description of the stratigraphy and lithology of the study is given in a general form, which is summarized in the figures 4 and 5.

3.2 Biostratigraphy

The biostratigraphic limit of Kazhdumi Formation (Figs. 4 and 5) at a time with the first appearance of Trocholinids in Sarvak Formation (Baumfalk and Willemsen, 1986; Baumfalk and Van Hinte, 1985). Eventually, the upper part of Sarvak Formation is marked by presence of Dicarinellids and other planktic forms in Gurpi Formation. Foraminifers zone of Kazhdumi Formation is called the Hemicyclammina sigali (Fig. 6g), Orbitolina assemblage zone (Fig. 4), which is characterized by the first presence of well diversified Orbitolina species such as, Orbitolina conica (Fig. 6c), Orbitolina discoidae, Orbitolina sp., Mesorbitolina aperta, Mesorbitolina subconcava (Fig. 6d), Mesorbitolina parva (Fig. 6e), Mesorbitolina texana co-occurring with the abundance of Hemicyclamina sigali throughout the section. Determined foraminifers of this zone are consisted of: Cuneolina pavonia, Edomia sp., Iraqi sp., Hedbergella sp., Marsonella trochus (Fig. 6f), Pseudolithuenella sp. There are many records (e.g., Rahiminejad and Hassani, 2016; Afghah et al., 2014; Shirazi et al., 2011) indicated that Mesorbitolina texana, Mesorbitolina subconcava (Fig. 7a), Mesorbitolina parva, Orbitolina discoidae, Daxia cenomana and Hemicyclammina sigali are assigned to Albian. Thus, Kazhdumi Formation is assigned Albian in age.

Three biozones in Sarvak Formation are found (Fig. 5). The established biozones are comprised of: 1-Orbitolina, Trocholina assemblage zone; this zone consists of the lower portion of the Sarvak Formation. This zone is described by disappearance of Hemicyclamina sigali and the presence of well diversified Trocholinids which are associated with Orbitolinids. This zone is extended about 40 meters and it consist of middle bedded limestone with marly limestone and thin bedded limestone interbedded with contain bivalves, gastropod and debris Rudist (Figs. 6h, and l). The common foraminifers and microfossils of this biozones consists of: algea. (Fig. 6l), Conica (Orbitolina) conica, Mesorbitolina texana (Fig. 7b), Iraqia sp., Dictyoconus pachimarginalis, Lenticulina sp. (Fig. 6m), Permocalculus sp. (Fig. 6k), Praelveolina cretacea, Pseudocyclammina rugosa (Fig. 6a), Pseudolithuenella reicheli, Clypeina sp. (Fig. 6j) Favosella washitensis, Globigerinelloides sp. (Fig.7 d, e), Muricohedbergella delrioensis, Hedbergella planispira, Hedbergella trochoidea, Hedbergella moremanni, Rotalipora sp. Textularia (Fig. 6b), Rotalipora ticinensis, Stomiosphera sphaerica (Fig. 8). Many documents confirm the Albian through Cenomanian age of the investigated faunal assemblage (e.g., Permoli Silva and Verga, 2004); whereas both Muricohedbergella delrioensis and Hedbergella planispira were previously recorded from early to Middle Cenomanian of northwest Syria by Ghanem and Kuss (2013). Also, it is necessary to note that Muricohedbergella delrioensis was documented as early to Middle Albian taxon and Muricohedbergella planispira was described as early Albian biozone from South Palmyrides, Syria by Ghanem et al. (2013). Moreover, Hemleben (2006) has been previously documented Pseudocyclammina rugosa as Cenomanian taxon. However, regards to identify foraminifers the age of this assemblage zone is referred to early Cenomanian (Figs. 4 and 5).

2-Nezzazata conica assemblage zone; this zone is described in the middle portion of Sarvak Formation which is has been specified by grey color thin-bedded limestone and then thick-bedded limestone. The thickness of this assemblage zone is measured approximately 25 meters. This zone is described by the presence of Nezzazata conica which associates with following types of foraminifers along this zone can be mentioned: Biplanta peneropliformis, Iraqia sp., Peneroplis sp., Prealveolina cretacea, Pseudolithuenella reicheli, Trocholina sp., and Textularids. Nezzazata conica have been previously recorded from Mid Cenomanian strata of south Zagros (Afghah and Fadaei, 2015). Velić (2007) documented Nezzazata conica as long-range taxon which is accompanied with Biplanta peneropliformis from Karst Dinarides. It is necessary to note that Pseudolithuenella reicheli was distinguished from mid to Late Cenomanian of the mentioned area (Velić, 2007). Husinec et al. (2000) have reported Nezzazata conica and Pseudolithuenella reicheli from Mid Cenomanian strata of northwest of Croatia. Therefore, it is approval of Mid Cenomanian age for this biozone.

Zone 3: Dicarinella algeriana, Rotalipora globotruncanoides assemblage zone. This assemblage is determined in the upper unit of Sarvak Formation (Fig. 5). The thickness of this zone is approximately 33 meters. It is described by grey thick-bedded limestone. This zone is identified by disappearance of Nezzazata conica which is coeval with the first occurrence of Dicarinella algeriana, Rotalipora globotruncanoides. The upper biostratigraphic limit of Dicarinella algeriana, Rotalipora globotruncanoides zone is not clear. Diagnosed foraminifers and other microfossils of this zone are consisted of: Favosella washitensis, Globigerinelloides sp., Muricohedbergella delrioensis, Hedbergella planispira (Muricohedbergella), Hedbergella trochoidea, Heterohelix moremanni, Hetrohelix sp., Rotalipora appenninica, Rotalipora ticinensis, and Stomiosphera sphaerica. Previous biostratigraphic data confirm that identified faunal assembalge of this biozone as Late Cenomanian age (e.g., Permoli Silva and Verga (2004); Ghanem and Kuss (2013); Afghah and Fadaei (2015)). Some of investigated taxa [Hedbergella planispira (Muricohedbergella), Heterohelix moremanni and Muricohedbergella delrioensis] have been recorded as long range of planktic taxa (Permoli Silva and Verga, 2004). Petrizzo et al. (2012) documented Hedbergella planispira (Muricohedbergella) from Aptian–Albian strata of Vocontian Basin (southeast France). However, by the faunal assemblage and the stratigraphic position of this zone seems correct the Late Cenomanian age.

The Kazhdumi Formation consists of three biozones in the studied section. 1- Orbitolina sp. Taxon rang zone: This biozone is consists of limestone with intercalation shale and marlstone foraminiferal speciemens orbitolinids, Mesorbitolina texana (Lower Albian Taxon), Mesorbitolina subconcava, calcareous algae and Millolidea. which has Albian age age (Wynd, 1965). Upper Aptian foraminifers (Neomeris sp.) are well developed in Orbitolina sp. Taxon rang zone. The lower Albian foraminifer assemblage is associated with Conicorbitolina conica (Schroeder et al., 2010). 2- Total Range Zone of Hemicyclammina sigali: This biozone is consisted of medium to thick limestone. This biozone with presence of Hemicyclammina sigali with algae, Conicorbitolina conica and Edomia iranica. The age of this biozone faunal assemblage suggests a middle Albian age. This faunal assemblage belongs to the Wynd (1965) zone number 17. Shirazi et al. (2011) and Van Buchem et al. (2010) have an association of the middle Albian.

Fig. 3. a) A panoramic view of the studied section, b) and c) close-up view of lower Kazhdumi and upper Kazhdumi Formation respectively.

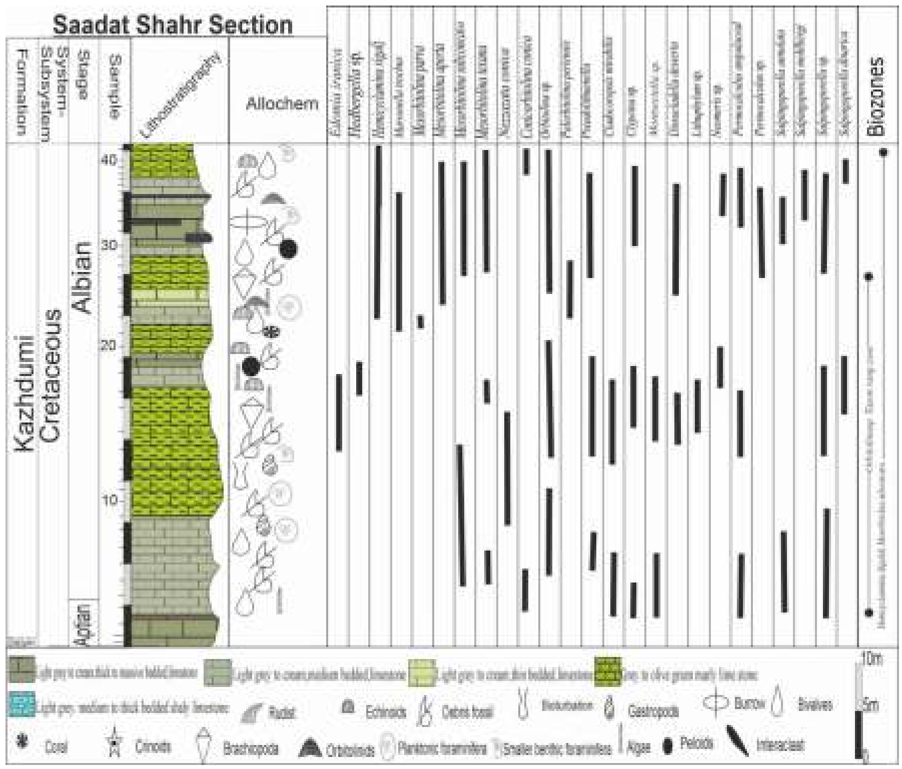

Fig. 4. Biozonation and lithostratigraphic column of the Kazhdumi Formation in the study area.

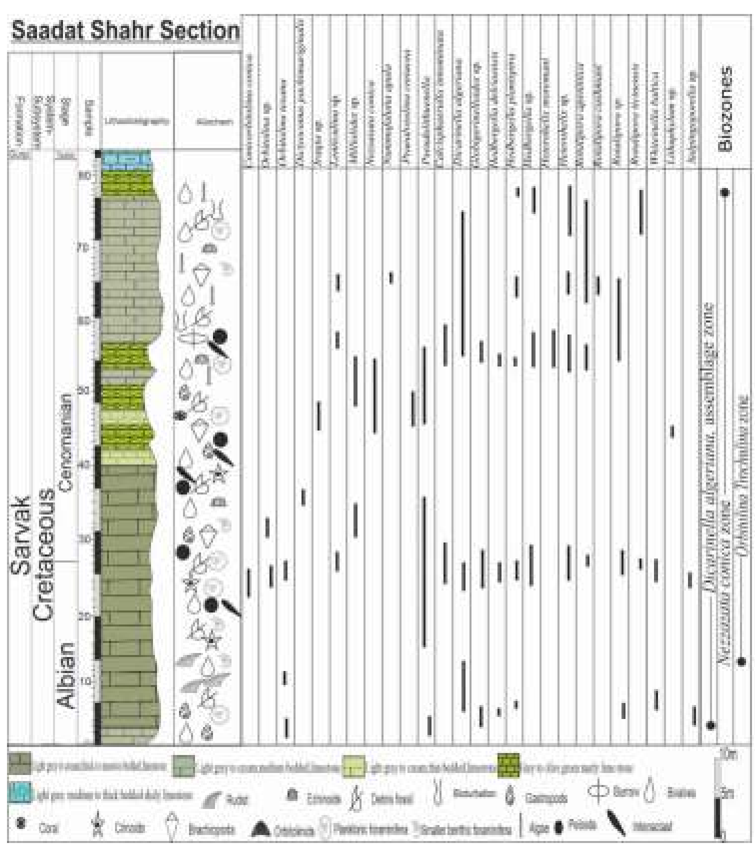

Fig. 5. Biozonation and lithostratigraphic column of the Sarvak Formation in the study area.

3.3 Microfacies analysis

The analogy comparison of the percentage of allochmes (skeletal and non-skeletal grains) in both Kazhdumi and Sarvak formations are shown in figure 6 (similar to method Flügel, 2009) and the following results are obtained. Considering the fact that the percentage (continue studying microfacies) of micrite is higher in Kazhdumi Formation, it is likely that during the formation of the microfacies, medium energy sedimentary basin conditions were found in the Kazhdumi Formation. By microscopic comparing of the two studied formations, the percentages and variability (foraminifera) of bioclasts in the formation of Sarvak Formation are much higher than Kazhdumi Formation, whereas well expand and diversified orbitolinids are recognized in Kazhdumi Formation. Increasing the percentage of bioclast in the Sarvak Formation supports those conditions for biomaterials in the Sarvak Formation have been further developed. The agglutinated foraminifers and other bioclast are well expanded in the Kazhdumi Formation, which indicates the paleo-ecological niche during the deposition. The rocks of sections are subcategorized into eleven various microfacies, that are considered by a dominating biogenic component (skeletal grains and calcareous algae) and non-skeletal components (intraclast and peloid) depositional texture. Based on sedimentary environment, three facies' associations can be identified: lagoon, tidal flat and open shallow marine. The Sarvak Formations are carbonate and dolomitic lithologic aspect. According to the investigated bioclasts (planktic foraminifera and other pelagic microfossils) the sequences are assigned to deeper environments (open marine). Microscopic investigation supports three major facies belt in the Sarvak Formation which are shelf major depositional systems.

3.3.1 Microfacies of the Kazhdumi Formation

In this study, four carbonate microfacies were identified for the Kazhdumi Formation, that are related to three inner and middle portions of a ramp depositional settings. Based on lithology, texture and fossil content, etc., there are seven types of microfacies in Sarvak Formation. From distal to proximal, four main facies belts of shallow open-marine, tidal flat Barrier and lagoon were differentiated.

MF1 Orbitolitna Bioclastic Packstone–Wackestone

This association of facies comprises of grey limestone interbedded marl. This facies is characterized by *Conicorbitolina conica, Mesorbitolina texana, Mesorbitolina subconcava*, milolids green, Peloids, *Salpingoporella* sp.), are recognized (< 5%). The matrix comprised of calcareous mud (micrite) and hardly sparite is distinguished. The faunal reflects a moderate water circulated lagoonal environments. Peloids mixed with other facies also create its presence. The occurrence of such microfacies is made in the inner or deeper realms of the ramp (Figs. 7o and s).

MF2 Foraminifera Algal Wackestone-Packstone

The microfacies is designated with high frequency of calcareous algae, echinoids, *Hedbergella* sp., *Daviesiconus* sp. in a wackestone and packstone with rare calcareous mud (as micrite) matrix (Figs. 7t and n). Furthermore, benthic foraminifers, Triloculina and rotaliids (*Neorotalia*? sp.), echinoids, green algae, in addition to debris of bivalves is in this microfacies. These microfacies are dominant of larger porcelaneous test and agglutinated and porcelaneous foraminifers such as miliolids and orbitolitids are assigned to the proximal inner ramp setting. Also, the orbitolinids are co-occur with conical and miliolids foraminifera which are referred to setting of shallowest proximal inner-ramp deposits. The presence of conical foraminifera and existing species indicates the low- moderate energy of the environment creating microfacies (Schroeder et al., 2010). Fossils echinoid and algea may have been shifted from shallow to deep setting of environments by sea currents. The deposition in inner lagoonal (shallowest) part of a carbonate ramp and the inner ramp setting is represented by this microfacies (Fig. 7).

MF3 Rudist Wackestone, Benthic Foraminifera

The foraminifera are the predominant skeletal grains (e.g., *Montseciella arabicus, Ticinella primula, Hemicyclammina sigali*). This microfacies is dominated by limy mud and lacks in neritic fauna of shallow water. Sedimentary features indicative of high sedimentation energy and shallow water level are not observed in this facie. The open marine lower part environment is due to increase of benthic foraminifera, the fine- grained matrix and the presence of smaller pelagic foraminifera. The deposition under the normal basement wave is an indicative of the low energy hydrodynamic regime (Geel, 2000; Flügel, 2009). The microfacies contain various community of rudist (40%), bivalves, gastropods, calcareous algae and other fossil debris that are usually strongly scratched on outer side of walls in matrix content of a packstone (Fig. 7p). This microfacie is resemble of the mid-distal inner ramp setting.

MF4 Bioclast Mudstone-Wackestone

It is not possible to identify the sediments of this microfacies and its fauna. Sub ordinate amount of detrial fosil debris is identified in some sample. This microfacies relates with upper Kazhdumi Formation. Lime mudstone with small fossil debris reveals that this facies was deposited in a confined shelf lagoon (Figs. 7q and r). Microscopic investigation indicates hypersaline conditions which refers to the shelf lagoon. The diversity of foraminifera represents a high energy environment in a shallow confined shelf lagoon. The occurrence of thin specks of bivalve, echinoid and ostracod (within a micritic groundmass) reveals of constrained environment of inner lagoon (Rasser et al., 2005).

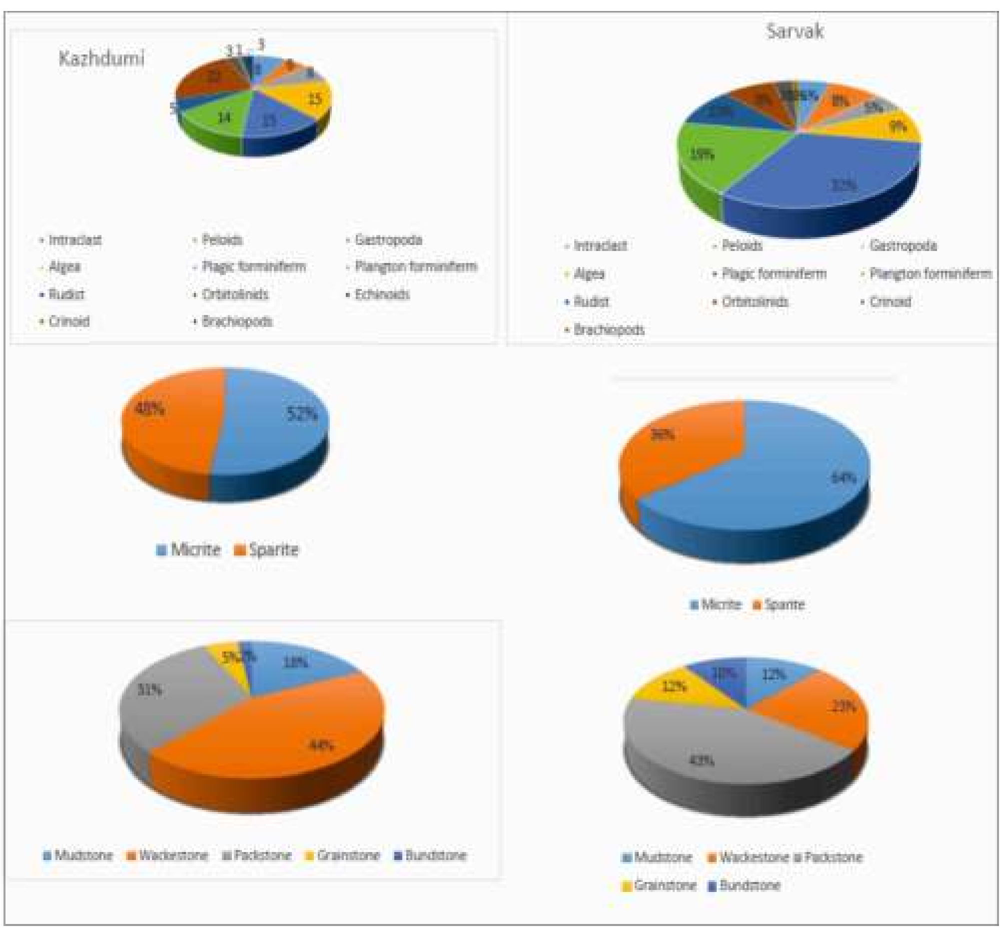

Fig. 6. Percentage of Allochem in Sarvak and Kazhdumi Formations.

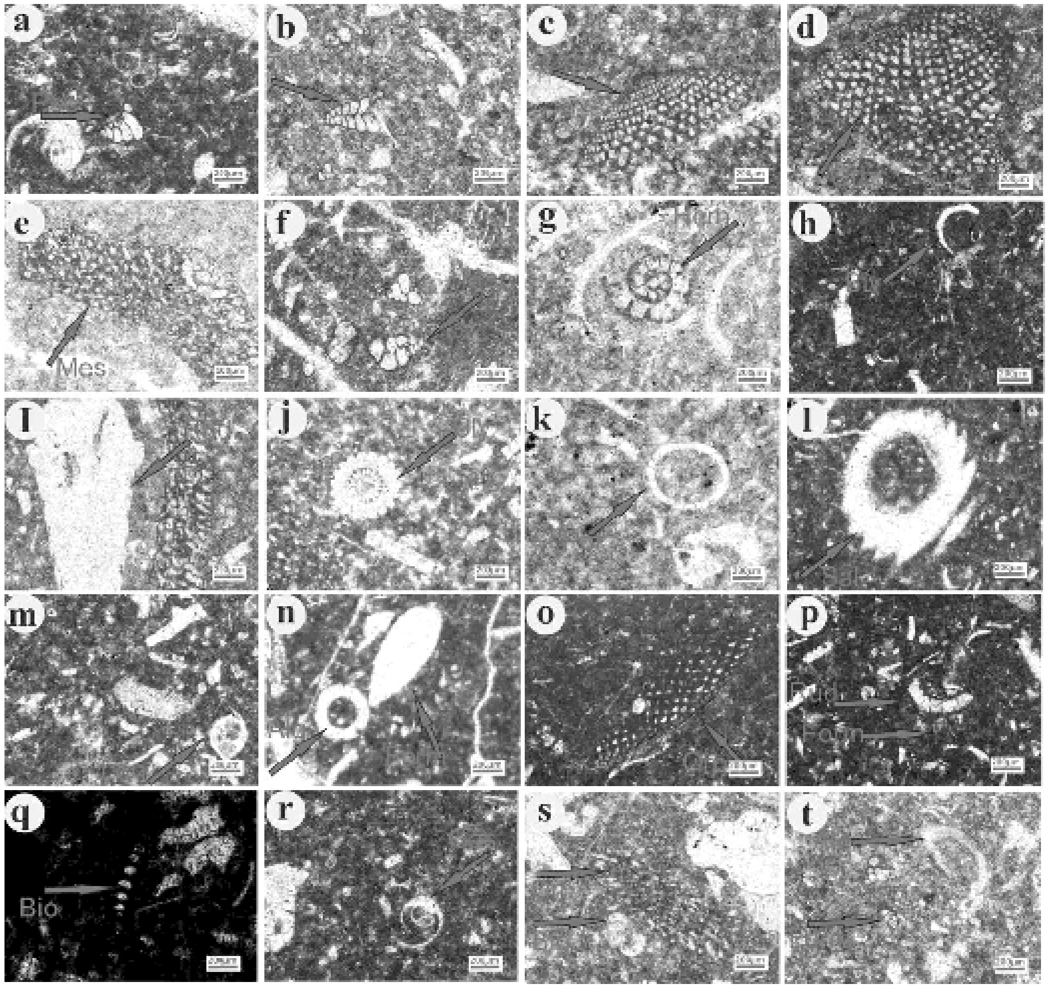

Fig. 7. Microscopic figures of identified foraminifers, calcareous algae and microfacies in the Kazhdumi Formation: a) *Pseudolithuenella* sp., b) Textularid, c) *Orbitolina* sp., d) *Orbitolina conica,* e) *Mesorbitolina subconcava,* f) *Marsonella* trochus, g) *Hemicyclammina sigali,* h) bivalves, i) Rudist debris, j) *Clypeina cf. algea,* k) *Permocalculus ampullaceal*, l) *Salpingoporella* sp., m) *Lentioculina* sp. Microfacies Kazhdumi Formation in study area, n) Foraminifera algal wackestone, foraminifer's packstone, o) *Orbitolina* bioclastic packstone- wackestone, p) Benthic foraminifera, rudist wackestone, q, r) Bioclastic mudstone-wackestone microfacies, s) Orbitolitna bioclastic packstone-wackestone microfacies (plankton is rarely recognized), and t) Foraminifera algal wackestone, foraminifer's packstone microfacies. (Arrows Pse: *Pseudolithuenella,* Tex: Textularid, Orb: *Orbitolina, Orbc: Orbitolina conica, Mes: Mesorbitolina subconcava, Mar: Marsonella trochus, Hem: Hemicyclammina sigali, Biv:* bivalves, Form: *foraminifera, Alg: algal, Cly: Clypeina cf. algea, Per: Permocalculus ampullaceal, Sal: Salpingoporella, Len:Lentioculina, Bio: Bioclast).*

3.3.2 Microfacies of Sarvak Formation

Mf5 Oligostegina Bioclast Wackestone-Packstone

Oligostegina are the main skeletal components of this microfacies (40%). The *Globigerina* sp. co-occurs with spherical or ovoid oligoteginids. Pelagic foraminifera recorded include *Ticinella* sp., *Hedbergella* sp., *Murichohedbergella delrioensis* and rarely benthic foraminifers such as: *Vavulamina* sp., and Small rotallids, associated with ostracods and echinoderms fragments as skeletal grains (50%) (Figs. 8f and g). They are generally identified as packstone with wackestone textures. The existence of very exceptional planktic and platform foraminifera (i.e., rotalids and remains of echinoid) reveals an environment of low-energy in a distal position below the calm weather wave base (Morshedian et al., 2012).

MF6 Pelagic Foraminifer's Wackestone–Packstone

In the large skeletal grains, this microfacies results as poor and contains fine grain fossil debris (30%). This microfacie contain (skeletal component) microfossil and Pelagic foraminifers e.g., *Ticinella* sp., Hedbergella sp., *Murichohedbergella delrioensis* and *Calcisphaerula innominate.* The mentioned microfacies indicating a marine environment of pelagic origin (Flügel, 2009; Scholle et al., 1983) that carried skeletal grains from shallow-water of adjacent areas. The sedimentary environment of this microfacies indicates an environment of open marine. This microfacies was observed in all sections (Figs. 8h and i).

MF7 Bioclastic Peloid Packstone

This microfacies is mostly observed in the middle part of Sarvak Formation. The bioclasts which are characterized by the occurrence of textularids, bivalve, ostracods and echinoid fragments as main skeletal grains. Additionally, Foraminifera (*Orbitolina* sp.and miliolid) and other skeletal grains (coral fragments, rare bryozoans) are commonly mixed with peloid (20%) (Figs. 8m and l). The existence of marine normal fossil including planktonic organisms, suggests conditions of open marine (Flügel, 2009). This microfacies was deposited in the shallower depth (Lagoon) toward barrier adjacent to microfacies peloidal wackestone microfacies.

MF8 Bioclastic Intraclast Aggregate packstone

These facies are characterized by a low energy element. The unique feature of this kind of microfacies is medium bed limestone with aggregate, skeletal grains and interclast are assigned to mollusca and fossil debris (30%). The bioclasts are surrounded in heterogeneous, greyish micritic calcareous mud as miciritic texture (20%) (Figs. 8n and o). According to Flügel (2009), aggregate packstone is typical of shallow water carbonate system environment, relatively calm littoral environments developed at the margins of ponds and channels and subject to intermittent currents and low sedimentation rates, indicated by fine cover.

MF9 Algal-Orbitolina Packstone

Calcareous algae are dominated by encrusting algae (contain Mesophyllum and Lithothamnion; 25%), that forms wavy crusts and are related with encrusting foraminifera and orbitolinids (Fig. 8p). The abundance and variety of increased benthic foraminifera is very low. Fine-grained micritic matrix is present and in addition, large and unregimented specimens are abundant (10%). Due to the presence of algae and other fossils this microfacies was deposited in lagoon environments (Geel, 2000, Flügel,2009). The low diversity of fauna (small rotalids and echinoid) confirms mentioned paleo-environment. No evidence of extended emergence, significant meteoric diagenesis and desiccation featured were recognized in the field.

MF10 Peloidal Packstone-Grainstone

These facies are distinguished by the abundance of peloids (maximum size 1 mm) and peloids. The matrix is mainly composed of micrite. Peloids are spherical, oval or angular and have good circulation and show poor to moderate classification. Other grains contain foraminifera (1–2 %) and bivalve debris (2–3 %) as skeletal components (Fig. 8j). The presence of the mentioned allocames indicates that they were deposited in a limited lagoon environment in close vicinity of relatively low currents tidal flats (e.g., Geel, 2000).

MF11 Intraclast Bioclatic Packstone-Grainstone

This microfacies is composed of intraclasts (25 %) fossil debris (3 %), and miliolids and bivalve fragments (1–2 %) (Fig. 8k). The very communal wackestone to packstones and peloidal resembles well-known low-energy, somewhat restricted environments of peritidal that episodically interrupted by high-energy events such as spring tides and storms. The presence and absence of allocems and larger foraminifera, texture, tissues, remains of algae, and open sea animals indicate a very shallow environment. A semi-arid climatic condition and restricted circulation of water partly led to restricted fauna hypersaline*conditions (Flügel, 2009) (Figs. 9 and 10).*

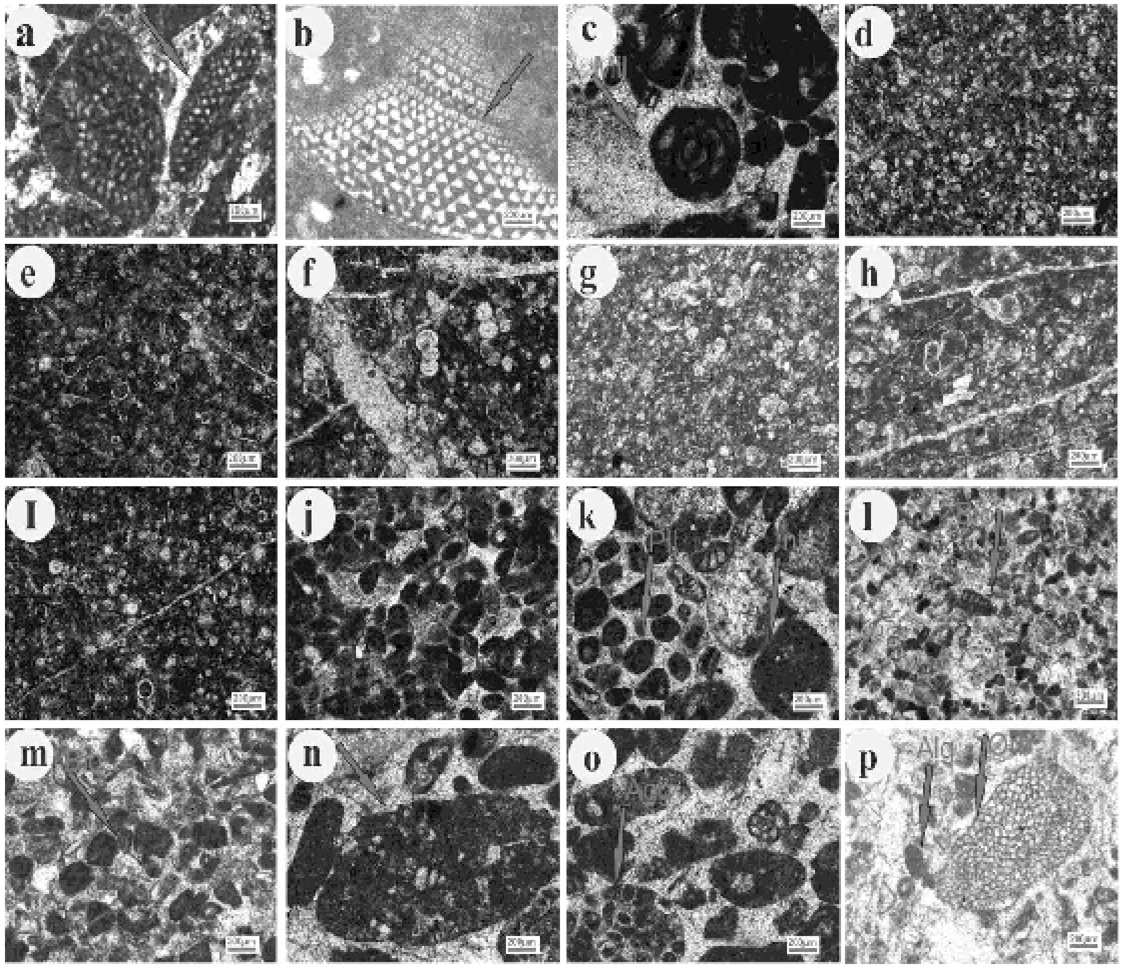

Fig. 8. Microscopic figures of identified microfossisl and microfacies in the Sarvak Formation: a) *Conicorbitolina conica*, b) *Mesorbitolina texana*, c) *Miliolides,* d) *Calcisphaerula innominata,* e) *Globigerinelloides* sp., f) *Hedbergella planispira,* g) *Hedbergella trochoidea.* Microfacies Sarvak Formation in study area, h, i) Pelagic foraminifer's wackestone-packstone microfacies, j) Peloidal grainstone-packstone microfacies, k) Intraclast bioclast grainstone microfacies, l) Bioclast peloidal grainstone and packstone microfacies, m) Bioclastic peloid grianstone-packstone microfacies (Rudist debris is shown by arrow), n, o) Bioclastic interclast aggregate grainstone, p) Algal *orbitolina* packstone microfacies. (Arrows Con:*Conicorbitolina conica*, Mes;*Mesorbitolina texana*, Mil: Miliolides, Int:Intraclast, Bio: Bioclast, Agg; Aggregate, Pll; peloidal).

3.4 Paleo-environmental change and sedimentary model

As the Afro-Arabian plate moved to equatorial latitudes, the warm and humid Jurassic climate conditions were replaced at the Jurassic-Cretaceous boundary (Roth and Baudler, 1981). The Cretaceous sequence consists of a series of sediments that form thin clastic carbonate intervals platforms during sea-level fall and rise (Sharland et al., 2001; Heydari, 2008; Van Buchem et al., 2010). During Aptian-Albian-Cenomanian times, the eastern part of the Arabian Plate (southwest Iran) It was found large intra shelf basins surrounded by shallow-water platforms (Figs. 10a and b). The sediments of the Kazhdumi and Sarvak formations were deposited on platforms and within the intra shelf basin on the passive margin of Zagros belt (Ziegler, 2001) (Fig. 9c). Therefore, the interpretation and extent of the facies and sedimentary environments of the Kazhdami and Sarvak shelf margins around the intra-shelf basin show important consequences. This study considers the Kazhdumi and Sarvak formations in the Interior Fars zone (Fig. 2c) in the northeast margin intra shelf basin (Fig. 10). The Kazhdumi Formation strata has been continuously deposited as a marly limestone and shaly limestone lithology with more abundant fossils in the depth of the open marine over the Dariyan Formation. The Kazhdumi Formation comprised of organic constituents particularly orbitolinids, indicating as a pale-oecological niche. Although dolomitization has occurred in the Sarvak Formation microfacies as dolomitic limestone, microfacies characteristics and depositional texture are preserved such as scattered fossil debris (Figs. 10b and c). On the basis of very small crystal size and fabric, absence of fossils, and depositional textures with original preservation, it is revealed that low-energy and near surface conditions (possibly in a lagoon to the tidal flat setting) are suitable for this dolomite formation. These facies were deposited in a restricted shelf lagoon. In the dolomitic limestone and mudstone facies, according to low rate of fossil remains and fine grain sediments, a low energy supratidal environment is evidenced. Lack of skeletal grains (bioclasts) in microfacies, unsuitable marine organism conditions and confirms a water cycle limit. The faint laminations in some thin limestones of Sarvak Formation are probably owing to microbial binding. Evidence reveals about an open marine environment close to seaward of barrier. Lack of detrital grains and presence of micrite, demonstrate to deposit it under wave base of low energy environment condition. The skeletal peloidal wackestone with bioclast (foraminifera) were deposited in a shallow lagoonal environment in the water depth of 10-20 m (Flügel, 2009). The presence of peloidal grains in the studied packestone microfacies indicates that deposition was made in an environment of shallow lagoonal and low energy. While, in poor connection with the fossils of low variety of open marine, demonstrate a deposition environment of shallow subtidal enclosed with slow sedimentation rate. The low diversity and high abundance of common marine fossils in bioclast wackestone indicates that the deposition was in a calm water and lagoonal environment (Nichols, 2009). In addition, there are high abundance of peloids in low energy water, warm, high calcium carbonate saturation and lagoon in the back of barrier (Adachi et al., 2004). Boundstone microfacies (Sarvak Formation) are formed in a high energy environment setting in the shelf by deriving the skeletal elements from contiguous facies. The absence of indicator fossils for the deeper facies suggests an internal ramp origin for the boundary rock layers, comprises with their stratigraphic close relationship to the Boundstone facies. It should be noted that well sorted skeletal limestone beds are inferred to be deposits in the inner ramp and the poorly sorted are attributed as storm deposits in the mid ramp. Due to the erosive nature of basal contact, the predominance of fining upward trends, the unidirectional flow, and the overall abundance of heterolithic facies with marine traces. This sedimentary environment detected at the base of the Sarvak and Kazhdumi Formation is considered as estuarine wave dominated system (Figs. 10a and b). Therefore, based on the gradual change in the environment of Kazhdami Formation, this formation was considered as a carbonate homoclinal ramp. Intraclast and peloid percentage is higher in Kazhdumi Formation and shows that Kazhdumi Formation in less stable conditions and less depths deposited. The Sarvak Formation deposited in an intra-shelf basin with the sedimentation of the oligostegina limestone and in shelf margin (carbonate inner toward outer ramp) conditions with rudist debris. The rudist debris enhances reservoir quality of the Sarvak Formation (Ghabeishavi et al., 2010). In Sarvak Formation, the transformation of shallow facies into deeper facies indicates the sea-level fluctuation as transgression, conversely, the transformation of the deeper facies into shallow facies indicates another sea-level fluctuation as a regression. Accordingly, the Sarvak Formation represents a complete sequence, which involves the beginning of a progression and lateral reversal and also a para sequence in the upper part of section, which shows only the transgression (Figs. 10a and b). Received facies data reveal seaward margin of carbonate ramp. Additionally, facies analysis reflects those deposits of the Sarvak Formation is referred to distally steepend type of carbonate ramp. Due to the presence of a plagic faunal assemblage is below surf zone which confirm outer ramp. The bioclastic packstone, fore reef with presence of intraclasts, boundestone rudist, Lagoon and tidal flat facies are marked as the inner ramp. Generally, these depositional sequences exhibit large-scale progradation from west to east.

There is a good correlation between the sequence subdivision proposed here and those reported by Van Buchem et al. (2010).

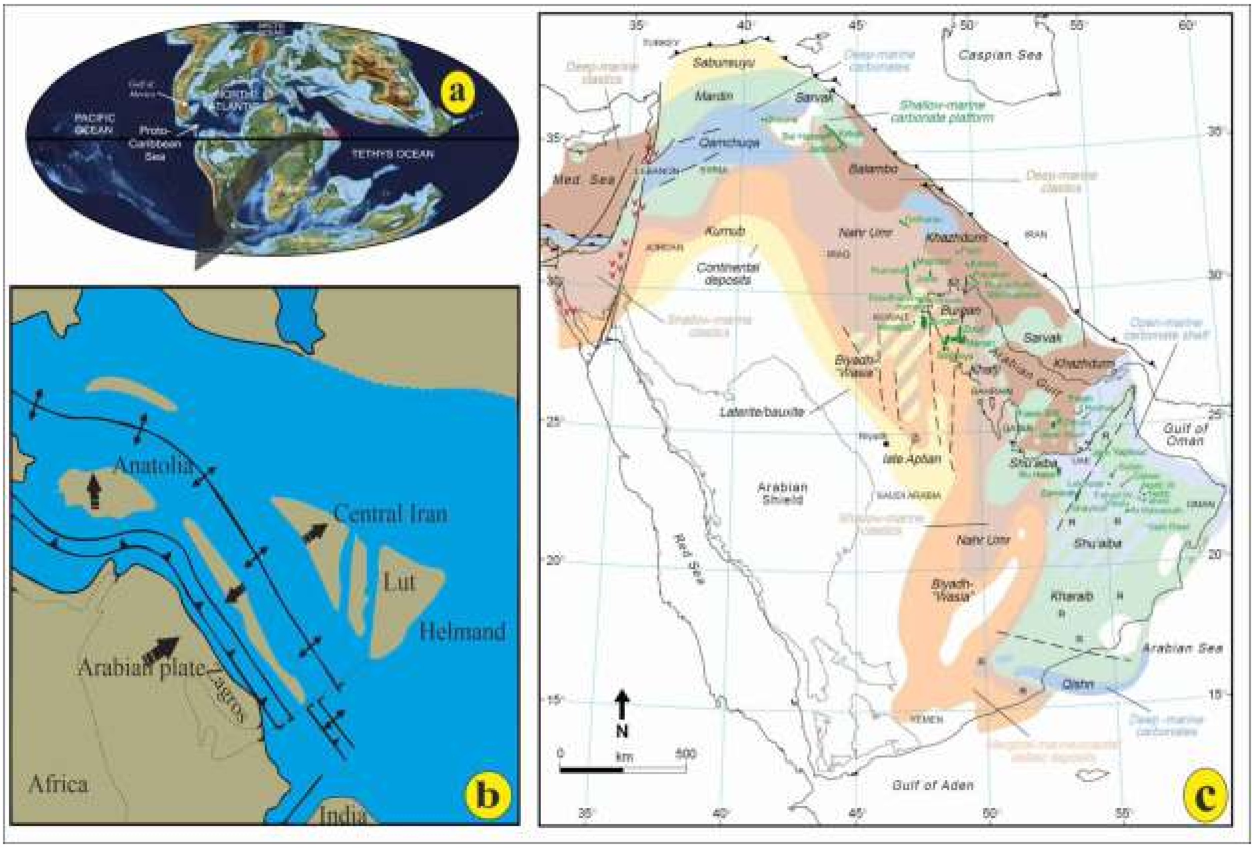

Fig. 9. a, b) Paleo-geographic map of Arabian Plate during the late Early Cretaceous (Ogg et al., 2016); and c) Lithofacies map and equivalents (regionally) of the late Early Cretaceous in Arabian plate of the Khazdumi and Sarvak formations (modified from Ziegler, 2001).

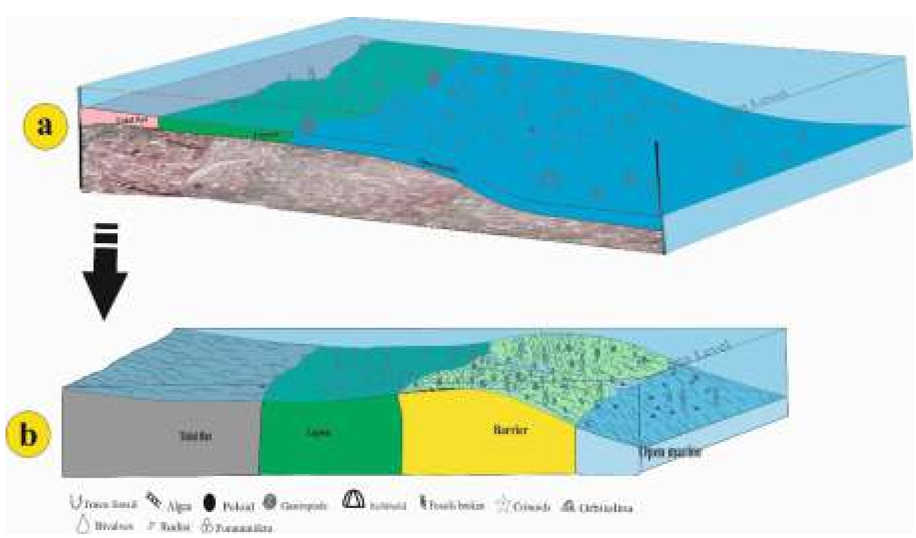

Fig. 10. Vertical facies distribution showing paleo-environment of the a) Kazhdumi Formation and b) Sarvak Formation at the study area.

4. Conclusions

Kazhdumi and Sarvak formations in the study area (Interior Fars) mainly consists of limestone, shale limestone. The architecture of facies and stratigraphy of Kazhdami and Saruk formations can be divided into the following lithofacies: a) gray to buffalo alternate shale and limestone, thin to thick bedded limestone with shale composition in Kazhsami Formation, b) alternative grey to buff shale and limestone, dark grey shale, intercalated grey shale in thin- to thick-bedded limestone in Saruk Formation. The biozones were encountered in the studied areas and the following seven assemblage zones have been defined. Stratigraphic distribution of identified foraminifers supports Albian to late Cenomanian age for the Kazhdumi and Sarvak formations in the study area. The ramp Kazhdumi Formation and shelf of the Sarvak Formation It has been deposited in the studied area. with a variety of carbonate facies. The trend of Kazhdumi and Sarvak formations in the study area shows that it was affected by the tectonic activities of the Zagros region and differs in lithology and facies from the folded Zagros in Fars zone. Based on collected facies data, sedimentation in the Kazhdumi and Sarvak formations deposits on a shelf and ramp setting, in a facies belts comprising of open marine, shoal, and lagoon. According to the microfacies and lithology information, the deposition of Kazhdami and Servak formations is made on the ramp and shelf, in the facies belt consisting of open marine, lagoon, and shoal. Eleven associated microfacies were identified based on the texture, lithology, sedimentary features, and biogenic components detected in the outcrops and from analysis of microfacies,

Authors Contribution

Massih Afghah, proposed the main concept, overall supervision of article content and involved in write up. Asiyeh Arampour, assisted in establishing sequence stratigraphy of the section, collected field data and editing images of article content. Mahnaz Parvaneh Nejad Shirazi, did provision of relevant literature, provide better suggestion for article content and review and proof read of the manuscript and did technical review before submission and proofread of the manuscript.

Acknowledgement

The authors are grateful to the editor and two anonymous reviewers for their instructive comments and suggestions.

References

Adachi, N., Ezaki, Y., and Liu, J., 2004. The fabrics and origins of peloids immediately after the End-Permian extinction, Guizhou Province, South China. Sedimentary Geology, 2, 161–178.

Afghah, M., and Fadaei H.R., 2015. Biostratigraphy of Cenomanian succession in Zagros area (southwest of Iran). Geosciences Journal, 19, 257–271.

Afghah, M., and Shabaanpour Haghighi, A., 2014. Aptian biostratigraphy in South Zagros Basin, southwest Iran. Geoscience Frontiers, 5, 277–288.

Afghah, M., and Dookh, R., 2014. Microbiostratigraphy of the Sarvak Formation in the east and north-east of Shiraz (Kuh-e-Siah and Kuh-e-Pichakan), SW of Iran. Journal of Sciences, Islamic Azad University, 24, 5-18 .

Aghanabati A., 2004. Geology of Iran, Geological survey of Iran, Terhan. 708p. (in Persian).

Alavi, M., 2004. Regional stratigraphy of the Zagros fold-thrust belt of Iran and its proforeland evolution. American Journal of Science, 304, 1–20.

Arzaghi, S., Khosrow-Tehrani K., and Afghah M., 2012. Sedimentology and petrography of Paleocene–Eocene evaporites: The Sachun Formation, Zagros Basin, Iran. Carbonates and evaporites, 27, 43–53.

Baumfalk, Y., and Willemsen, F., 1986. Ecophenotypic variation of the Orbitoides apiculata from the Maastrichtian stratotype. Geologie Mijnbouw, 65, 23–24.

Baumfalk, Y.A., and Van Hinte, J. E., 1985. Orbitoides media (d'Archiac) in the Campanian deposits of the A 10 Motorway at Mirambeau (Charente Maritime). Cretaceous Research, 6, 181–189.

Berberian, M., 1995. Master “blind” thrust faults hidden under the Zagros folds: active basement tectonics and surface morphotectonics. Tectonophysics, 251, 193–224.

Caron, M., 1985. Cretaceous planktic foraminifera. In: Bolli, H.M., Saunders, J.B., and Perch-Nielsen, K., (Eds.), Plankton stratigraphy. Cambridge University Press, 17–86 pp.

Coccioni, R., and Premoli Silva, I., 1994. Planktonic foraminifera from the Lower Cretaceous of Rio Argos sections (Sothern Spain) and bio stratigeraphic implications. Cretaceous Research, 15, 645–687.

Coccioni, R., Premoli Silva, I., Marsili, A., and Verga, D., 2007. First radiation of Cretaceous planktonic foraminifera with radially elongate chambers at Angles (Southeastern France) and biostratigraphic implications. Revue de Micropaleontology, 50, 215–224.

Dunham, R.J., 1962. Classification of carbonate rocks according to depositional texture. American Association of Petroleum Geologist Memoirs, 1, 108-121.

Embry, A.F., and Klovan, J.E., 1971. A Late Devonian reef tract on Northeastern Banks Island, NWT. Canadian Petroleum Geology Bulletin 19, 730-781.

Flügel, E., 2009. Microfacies analysis of limestone: analysis, interpretation and application. Berlin: Springer, 976p.

Gasiński, M.A., 1983. Albian and Cenomanian planktic foraminiferida from the Trawne Beds (Pieniny Klippen Belt, Polish Carpathians. Cretaceous Research, 4(3), 221–249.

Geel, T., 2000. Recognition of stratigraphic sequences in carbonate platform and slope deposits: empirical models based on microfacies analysis of Palaeogene deposits in southeastern Spain. Palaeogeography, Palaeoclimatology, Palaeoecology, 155(3-4), 211-238 .

Ghabeishavi, A., Vaziri-Moghaddam, H., Taheri, A., and Taati, F., 2010. Microfacies and depositional environment of the Cenomanian of the Bangestan Anticline, SW Iran. Journal of Asian Earth Sciences, 37, 275–285.

Ghanem, H., and Kuss, J., 2013. Stratigraphic control Levant Platform, Coastal Range, northwest Syria. GeoArabia, 18, 85–132.

Ghavidel-Syooki, M., 2003. Palynostratigraphy of Devonian sediments in the Zagros Basin, southern Iran. Review of Palaeobotany and Palynology, 127, 241-268

Hemleben, C., Olsson, R.K., and Pearson, P., 2006. Wall textures of Eocene planktonic foraminifera. Atlas of Eocene Planktonic Foraminifera, 47-66 .

Heydari, E., 2008. Tectonics versus eustatic control on supersequences of the Zagros Mountains of Iran. Tectonophysics, 451, 56–70.

Husinec, A., Velić, I., Fucek, L., Vlahović, I., Matičec, D., Ostrić, N., and Korbar, T., 2000. Mid Cretaceous orbitolinid (Foraminiferida) record from the islands of Cres and Losinj (Croatia) and its regional stratigraphic correlation. Cretaceous Research, 21, 155–171.

James, G.A., and Wynd, J.G., 1965. Stratigraphic nomenclature of Iranian oil consortium agreement area. American Association of Petroleum Geologist Bulletin, 49, 2182-2245.

Kalantari, A., 1976. Microbiostratigraphy of the Sarvestan area, southwestern Iran: National Iranian Oil Company.

Mohammadi, E., Safari, A., Vaziri-Moghaddam, H., Vaziri, M.R., and Ghaedi, M., 2011. Microfacies analysis and paleoenviornmental interpretation of the Qom Formation, South of the Kashan, Central Iran. Carbonates and Evaporites, 26, 210-255.

Morshedian, A., MacEachern, J.A., and Dashtgard, S.E., 2012. Integrated ichnology, sedimentology and stratigraphy of the Lower Cretaceous Sparky alloformation (Mannville Group), Lloydminster area, west-central Saskatchewan, Canada. Bulletin of Canadian Petroleum Geology, 60, 69-92 .

Motiei, H., 1995. Petroleum geology of Zagros. Geological Survey of Iran, 589 P.

Neagu, T., 2005. Albian Foraminifera of the Romanian Plain. Planktonic Foraminifera. Acta Palaeontologica Romania, 5, 311–332.

Nichols, G., 2009. Sedimentology and stratigraphy. John Wiley and Sons, 335p.

Ogg, J.G., Ogg, G., and Gradstein, F.M., 2016. A concise geologic time scale: Elsevier.

Opera, A., Alizadeh, B., Sarafdokht, H., Janbaz, M., Fouladvand, R., and Heidarifard, M. H., 2013. Burial history reconstruction and thermal maturity modeling for the middle Cretaceous-early Miocene petroleum system, southern Dezful Embayment, SW Iran. International Journal of Coal Geology, 120, 1-14.

Permoli Silva, I., and Verga, D., 2004. Prctical manual of Cretaceous planktonic foraminifera. International school on planktonic foraminifera, Perugia, Italy, 283p.

Petrizzo, M.R., Huber, B.T., Gale, A.S., Barchetta, A., and Jenkyns, H.C., 2012. Abrupt planktic foraminiferal turnover across the Niveau Kilian at Col de Pré-Guittard (Vocontian Basin, southeast France): new criteria for defining the Aptian/Albian boundary. Newsletters on Stratigraphy, 45, 55–74.

Premoli Silva, I., Caron, M., Leckie, R.M., Petrizzo, M.R., Soldan, D., and Verga, D., 2009. Paraticinella n. gen. and taxonomic revision of Ticinella bejaouaensis Sigal, 1966. The Journal of Foraminiferal Research, 39, 126–137.

Rahiminejad, A.M., and Hassani, M.J., 2016. Paleoenvironmental distribution patterns of orbitolinids in the Lower Cretaceous deposits of eastern Rafsanjan, Central Iran. Marine Microplaeontology, 122, 53–66.

Rasser, M.W., Scheibner, C., and Mutti, M., 2005. A paleoenvironmental standard section for Early Ilerdian tropical carbonate factories (Corbieres, France; Pyrenees, Spain). Facies, 51, 218-22 .

Roth, P.H., and Bowdler, J.L., 1981. Middle Cretaceous Calcareous Nannoplankton, Biogeography and Oceanography of the Atlantic Ocean. Society of Economic Paleontology and Mineralogy, Tulsa, Special Publication, 32, 517–546.

Scholle, P.A., Bebout, D.G., and Moore, C.H., 1983. Carbonate Depositional Environments: American Association of Petroleum Geologists Memoir, 33.

Schroeder, R., van Buchem, F.S., Cherchi, A., Baghbani, D., Vincent, B., Immenhauser, A., and Granier, B., 2010. Revised orbitolinid biostratigraphic zonation for the Barremian–Aptian of the eastern Arabian Plate and implications for regional stratigraphic correlations. GeoArabia (Special Publication), 4, 49-96 .

Sharland, P.R, Archer, R., Casey, D.M., Davies, R.B., Hall, S.H., Heward, A.P., Horbury, A.D., and Simmon, M.D., 2001. Arabian Plate Sequence Stratigraphy. Geo- Arabia Special Publication 2. Oriental Press, Manama Bahrain, 371 p.

Shirazi, Parvane-Nejad N., and Abedi, F., 2013. Lower Cretaceous orbitolinid (Foraminiferida) record from the southwest of Iran (Zagros, Shiraz). Open Journal of Geology, 3, 1–6.

Shirazi, Parvane-Nejad, N., Bahrami, M., Rezaee, B., and Ghahramani, S.H., 2011. Microbiostratigraphy of Kazhdumi Formation in the Northwestern Shiraz (Southwest Iran) on the Basis of Foraminifera and Calcareous Algae. Acta Geologica Sinica, 85, 777–783.

Van Buchem, F.S.P., Baghbani, D., Bulot, L.G., Caron, M., Gaumet, F., Hosseini, A., Keyvani, F., Schroeder, R., Swennen, R., Vedrenne, V., and Vincent, B., 2010. Barremian e lower Albian sequence stratigraphy of southwest Iran (Gadvan, Dariyan and Kazhdumi formations) and its comparison with Oman, Qatar and the United Arab Emirates. In: van Van Buchem F.S.P., Al-Husseini M.I., Maurer F., Droste H.J., (Eds.), Barremian e., Aptian Stratigraphy and Hydrocarbon Habitat of the Eastern Arabian Plate, 2. GeoArabia Special Publication 4, Gulf PetroLink, Bahrain, 503–548 pp.

Velić, I., 2007. Stratigraphy and Palaeobiogeography of Mesozoic Benthic Foraminifera of the Karst Dinarides (SE Europe)-Part 1. Geologia Croatica, 60, 1–60.

Verga, D., and Permoli Silva, I., 2003. Early Cretaceous planktonic foraminifera from the Tethys: the large, many-chambered representatives of the genus Globigerinelloides. Cretaceous Research, 24, 661-690 .

Verga, D., and Permoli Silva, I., 2005. Early Cretaceous planktonic foraminifera from the Tethys: The Upper Aptian, planispiral morphotypes with elongate chambers. Cretaceous Research, 26, 239-259.

Vincent, B., Van Buchem, F.S.P., Bulot, L.G., Immenhauser, A., Caron, M., Baghbani, D., and Alain, Y.H.A., 2010. Carbon-isotope Stratigraphy, Biostratigraphy and Organic Matter Distribution in the Aptian e Lower Albian Successions of Southwest Iran (Dariyan and Kazhdumi Formations). GeoArabia Special Publication 4, Gulf Petro Link, Bahrain 1, pp. 139–197.

Wynd, J.G., 1965. Biofacies of the Iranian Oil Consortium Agreement Area. Iran Oil Company Report No. 1082, 82p. (Unpublished).

Ziegler, M.A., 2001. Late Permian to Holocene paleofacies evolution of the Arabian plate and its hydrocarbon. GeoArabia, 6, 445–504.