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Biostratigraphy and palaeodepositional model of the Sarvak Formation in the Fars Zone, Zagros, Iran

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Abstract

This study is scoped on biostratigraphy, and palaeodepositional analysis of the Sarvak Formation, Fars Zone, and Zagros, Iran. The biostratigraphy and microfacies of this Formation form four field sections, are discussed. The Sarvak Formation in the study area is located on Kazhdumi Formation and below the Gurpi Formation and comprise of cream to grey medium bedded to massive limestone. Seven foraminiferal assemblages have been identified from the Sarvak Formation and these assemblages form the basis of the biostratigraphy. The lower and upper parts of Sarvak Formation are lacking diagnostic microfossils and based on their stratigraphic position, Late Albian-Late Cenomanian, ages was assigned respectively. Field and microscopic data led to the identification of five facies groups; Planktonic foraminifera-dominated facies, Benthic foraminifera-dominated facies, Rudist facies, Orbitolina facies and Mudstone facies, these facies were subdivided into twelve subfacies, which were grouped into three depositional environments: inner, middle and outer shelf and overall representing a shelf setting. Facies changes during the Late Albian-Late Cenomanian were generally associated with carbonate shelf models. These containing a number of separate aspect, namely: Orbitolina conica sp.-dominated shelf with minor Orbitolina sp. during the Late Albian, a Trocholina sp. and Conicorbitolina -dominated shelf during the Late Albian, a Rudist- to algae-dominated shelf during the most of the Early Cenomanian and a pelagic and benthic foraminifera-dominated shelf during Late Cenomanian. In general, from the Kuh-e- Gadvan section to the southwest of the Fars zone (Rashtanu section), the depth of the sedimentary basin of Sarvak Formation increased.

Keywords: Fars zone, Albian-cenomanian, Sarvak formation, Biostratigraphy, Facies.

1. Introduction

Sarvak Formation (Upper Cretaceous) in Fars zone ordinarily take place in structurally separated from units. The Sarvak Formation derives its name from the Tang-e-Sarvak (Bangestan Mountain), west of the Izeh zone. James and Wynd (1965) summarised antecedent standpoint and eventually formally determined the Sarvak Formation. Sarvak Formation is part of Bangestan group in Zagros (Fig. 2). Several large Cretaceous palaeogeographic units are identified together with the northern margin of Arabian plate and these units are ordinarily delimited by important tectonic discontinuities, covering today's Iran, Iraq, Saudi Arabia and the surrounding countries of Persian Gulf. The Sarvak Formation has stratigraphic equivalents in other countries, for example, Mishrif Formation in the UAE (e.g., Van Buchem et al., 2002), the Natih Formation in Oman (Van Buchem et al., 2002), Shilaif and Khatiyah Formations in the UAE and Qatar, and Ahmadi Member in Iran (Ghazban, 2007, Alsharhan and Nairn 1988, Nairn and Alsharhan 1997) (Fig. 2). Recent local investigations on the biostratigraphy, sequence stratigraphy, paleo-environment contained those by Taghavi et al., 2006; Beiranvand et al., 2007; Farzipour-Saein et al., 2009; Ghabeishavi et al., 2009; Hajikazemi et al., 2010; Razin et al., 2010; Van Buchem et al., 2011; and Asadi Mehmandosti et al., (2013) examined the Sarvak Formation based on qualification paleo-environment stratigraphy of the Sarvak Formation. We have examined four sections (Kuh-e-Gadvan, Sepidar, West Aghar and Rashtanu sections) in order to comparison the stratigraphic ranges and to supply a better stratigraphic range of the Sarvak Formation (Fig. 4). In this paper we provide a generalised lithological description and biostratigraphy for each section (Fig. 1). This paper is study on biostratigraphy, facies and palaeodepositional of the Sarvak Formation in the four sections studied and is contribute to the biostratighrapghic range of the formation in different parts of the Fars zone.

2. Geological setting

The Zagros belt stretch in a southeast–northwest demeanor from southeast Turkey in the northwest to the north of the Hormozgan area in South East Iran. The Zagros fold and thrust Zagros belt apportioned to a number of areas (Lurestan, Abadan plain, Hinterland Bandar Abbas, Izeh, Dezful Embayment, Fars, High Zagros), Which differ in their structural and palaeogeographic style (Motiei, 1993) (Fig. 1A). The study area is located in Fars region (Interior, Subcoastal and coastal) and the boundary of the interior Fars zone and High Zagros zone (Fig. 1B). Long strike-slip faults and salt domes, short faults (which cross-cuts these) and lines of structural and stratigraphic origin are typical structural elements in the area and have a low morphology. The Fars region is delimited by the Great Zagros Fault to the north and east, the Kazerun Fault to the west, and the Zagros Front Fault to the east (Fig. 1A). Succession of Cretaceous are extensived in Zagros basin, and the presence of Lower and Upper Cretaceous strata in far zone has long been established. The passive margin of the Sarvak Formation was generally covered by shallow marine, but a number of deep shelf basins were produce during the Cretaceous (Morris, 1980). The Sarvak Formation is one of the most productive oil reservoirs in south-western Iran (Ghabeishavi et al., 2009) that is Albian to Turonian (Razin et al., 2010).

3. Methods

The purpose of this study was to evaluate the fieldwork and laboratory investigation of the Sarvak Formation in Zagros region (Fars region) in southwestern Iran. Around 280 samples were collected for microfacies studies to improve the field data. Thin sections for facies analysis under the microscope have been identified and sedimentary environments have been identified and compared with paleo-environments (e.g., Wilson, 1975; Flugel, 2010). The limestones are arranged according to the design of the texture of Dunham's (1962). Facies Interpretation of facies was based on the underlying characteristics including grain size, grain composition, sedimentary texture, regular adjustment of energy index and fossil components.

The combined use of fossil-containing facies results in high- quality correlations for the beds of the Sarvak Formation throughout the depressive sections and provides support for detailed sedimentary environments.

4. Biostratigraphy and lithology

Biostratigraphic zonation for the Sarvak Formation was first identified by Wynd (1965), and later reviewed by Khalili (1976) however, in unpublished reports only. In this paper, biozonation and the test shapes of the largest benthic foraminifera are identified using previous work such as: Van Hinte (1976), Wynd (1965), Sigal (1977), Caron (1985), Hardenbol et al. (1998), Nishi et al. (2003), Silva and Sliter, (1999) and Premoli Silva and Verga (2004). Five foraminiferal assemblages were identified in the studied areas and these are shown in the Figures 3, 4 and 5 and Table 1. This study provide for the finding of previous research (Wynd, 1965) which showed that Late Albian-Late Cenomanian age for the Sarvak Formation in Fars Zone of the Zagros Basin (Fig. 1).

4.1. Kuh-e-Gadvan section

The Sarvak Formation at the Kh-e-Gadvan section is 292 meters in thickness. At the base, it comprises of thin to thick bedded cream to dark grey limestone with bioclast remains. In the middle part, medium to thick beds of limestone are predominant. Bioturbated features, bioclasts remain (debris fossil) and nodular structures are common. Towards the top, the formation remains thick to massive bedded bioclasts debris (bivalves, gastropod and debris fossil), and stylolite are present. According to vertical distribution of index foraminifers of this Formation in Kuh-e-Gadvan section, presence of different species and genera of benthic foraminifers is identified and indicated in Figure 4 and Table 1. The following foraminiferal assemblages were identified in this section: Favuselle washitensis-Oligosteginids, Simplalveolina simplex – Orbitolina conica and Praealveolina cretacea – Nezzazata conica assemblage zone, Rudist debris range and Cisalveolina lehneri zone. According to these biozonations, the , sediments attributed to the late Albian are actually to the late Cenomanian in age Wynd (1965).

Fig. 1. Location map of the study area and measured stratigraphic sections in the Zagros Basin, Iran (south of Fars area). (A) Tectonic zones of the Zagros area (Motiei, 1995). The Zagros area is divided into three tectonic zones from northeast to southwest: The High Zagros (Zone of tectonic activity), the Zagros simply folded belt and the Zagros foredeep zone (Stocklin, 1968). The Zagros simply folded belt is subdivided according to its tectonic and sedimentary evolution into three domains: Lurestan, Izeh and Fars areas (Motiei, 1995). The Fars area is separated into four sectors: coastal, subcoastal, interior Fars and Bandar Abbas Hinterland. (B)Close-up view of the locations of measured sections.

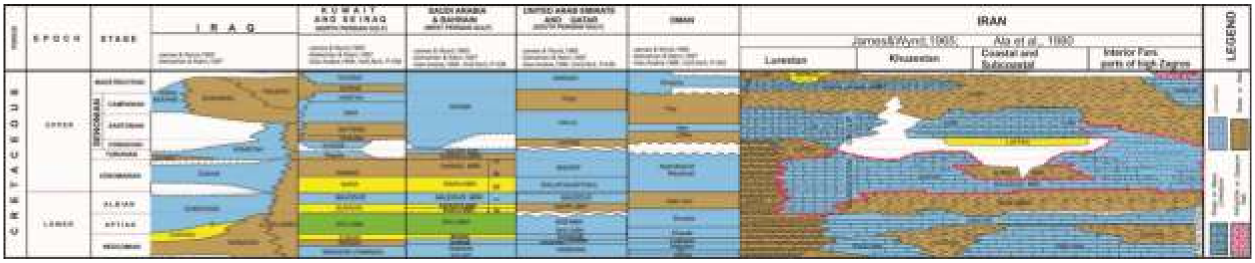

Fig. 2. Stratigraphic nomenclature for the Cretaceous in the eastern Arabian Plate (modified from Motiei, 1995) and lower and upper formation of the Sarvak Formation in the Zagros basin

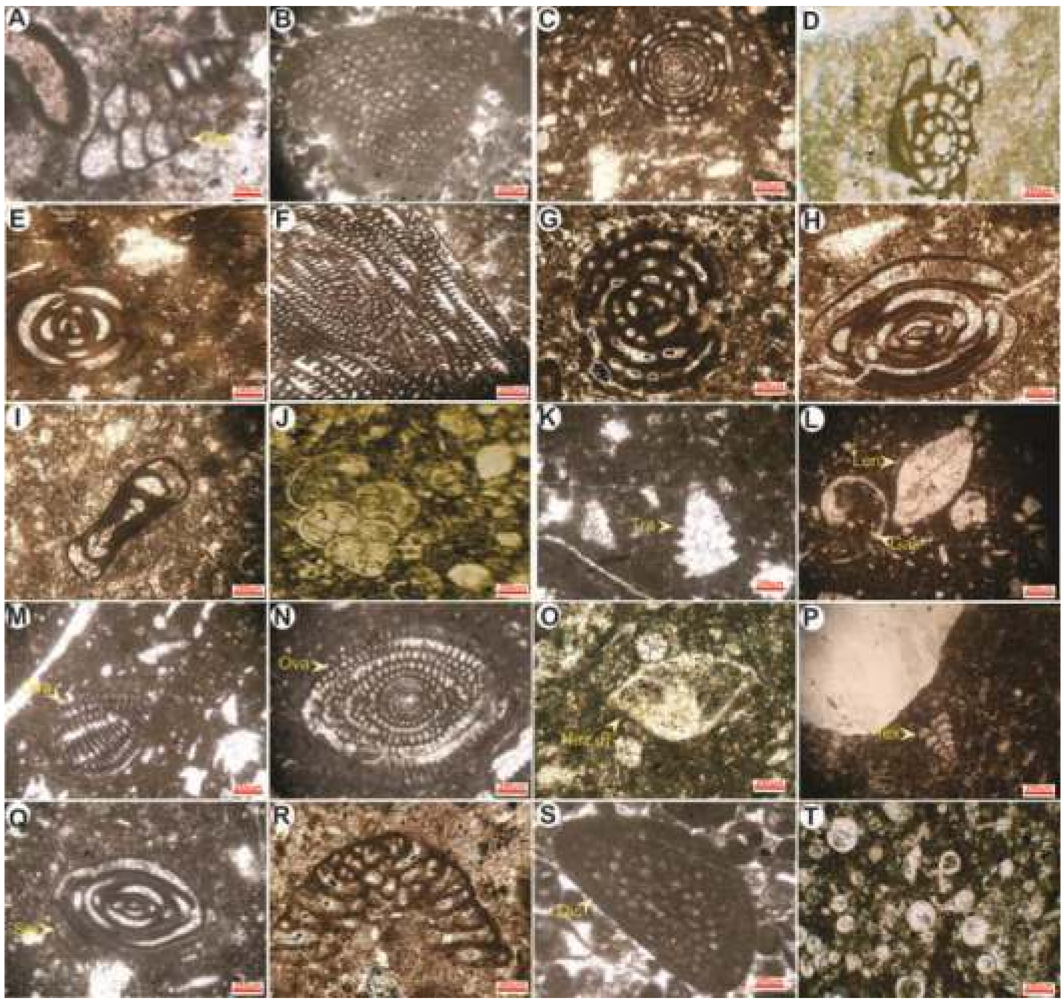

Fig. 3. Compilation of microscope photographs showing the main biostratigraphy characteristics of facies associations observed in the Sarvak Formation deposits in study area. (A)Textolaria sp. in Kuh-e-Gadvan section. (B) Orbitolina sp. in Rashtanu section. (C) Cisalveolina lehneri in West Aghar section. (D) Praealveolina simplex in Rashtalu section. (E) Quinqueloculina sp. in Kuh-e- Gadvan. (F) Praealveolina cretacea. In West Aghar section. (G Cisalveolina lehneri in Rashtanu section. (H)Spiroloculina cretacea in Rashtalu section. (I) Nummoloculina regularis in Kuh-e-Gadvan. (J) Heterohelix reussi and Echnoid in West Aghar section (K) Trocholina altispira in Kuh-e-Gadvan. (L) Gastropod and Lenticulina sp. in Sepidar section. (M) Ovalveolina sp. In Rashtanu section. (N) Ovalveolina sp. In West Aghar section. (O) Nezzazata picardi in west Aghar. (P) Textularia sp. in Sepidar section. (Q) Spiroloculina cretacea in Rastanu section. (R) Coxites zubairensis in Kuh-e- Gadvan section. (S) Dictyoconus sp. in Sepidar section. (T) Calcisphaerula innominata, Stomiosphaera sphaerica in Kuh-e- Gadvan section.

Table 1. Summary of characteristics of biostratigraphy in the Sarvak Formation in study area.

Stage	Foraminiferal assemblage	Age	Assemblage zone	Zone history	Location			
					Kuh-e-Gadvan	Sepidar	West Aghar	Rashtanu
Late Albian-Early Cenomanian	Ticinella madecassiana – Calcisphaerula sp. – Stomiosphaera sphaerica – [illegible] – Favusella washitensis – Globigerinelloides sp. – Hedbergella planispira – [illegible] sp. – Muricohedbergella [illegible] – Stomiosphaera conoidea	102 to 100Ma.	Favusella washitensis – Oligostegina assemblage zone	Wynd, 1965; [illegible]; Postuma, 1971; Sliter, 1989; Caron, 1985	✓		✓	✓
Late Albian-Early Cenomanian	Ticinella madecassiana – Dicyclina schlumbergeri – Pseudolituonella reicheli – Calcisphaerula innominata – Stomiosphaera sphaerica – Rotalipora sp. – [illegible] – Hedbergella [illegible] – Dictyoconus arabicus – Orbitolina sp.	99 to 101Ma.	Simplalveolina simplex – Orbitolina conica assemblage zone	Wynd, 1965; [illegible]; Robaszynski and Caron, 1996	✓	✓	✓	✓
Early Cenomanian	Nezzazata conica – Lenticulina sp. – Rudist debris – Textularia sp. – Pseudolituonella sp.	98 to 100Ma.	Rudist debris range zone	Wynd, 1965; [illegible]; Postuma, 1971; Sliter, 1989	✓	✓	✓	✓
Middle Cenomanian	Biradia sp. – Pseudolituonella reicheli – Quinqueloculina sp. – Chrysalidina gradata – Merlingina cretacea – Trocholina sp. – Rudist debris – Echinoderm & Gastropoda fragments – Dicyclina schlumbergeri – Pseudolituonella reicheli – Miliolidae – Orbitolina sp. – Ovalveolina cf. ovum	95 to 98Ma.	Cisalveolina lehneri zone	Caron, 1985; Robaszynski and Caron, 1996	✓	✓		✓
Late Cenomanian	Nezzazatinella picardi – Nezzazata sp. – Textularia – Nummoloculina – Dictyoconus – Dicyclina schlumbergeri – Pseudolituonella reicheli – Quinqueloculina sp. – Chrysalidina gradata – Merlingina cretacea – Trocholina sp. – Cuneolina cf. pavonia – Nezzazata conica – Praealveolina cretacea – Textularia sp.	93 to 95Ma.	Praealveolina cretacea – Nezzazata conica assemblage zone	Wynd, 1965; [illegible]; Postuma, 1971; Sliter, 1989	✓		✓	✓

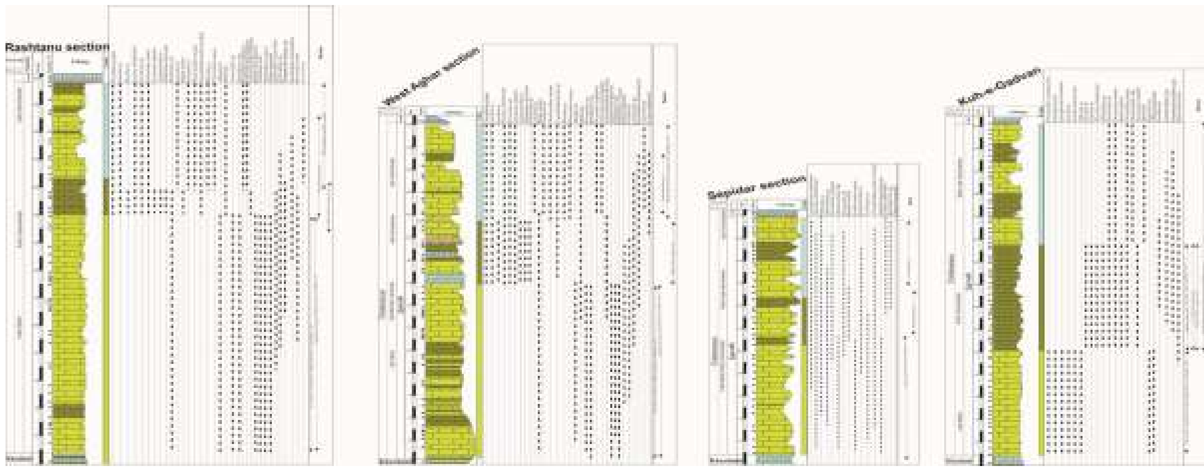

Fig. 4. Biostratigraphic column, abundance and range of foraminifera and other fossils for the Sarvak Formation in Study area, Interior and subcoastal Fars of the Zagros Basin, Iran.

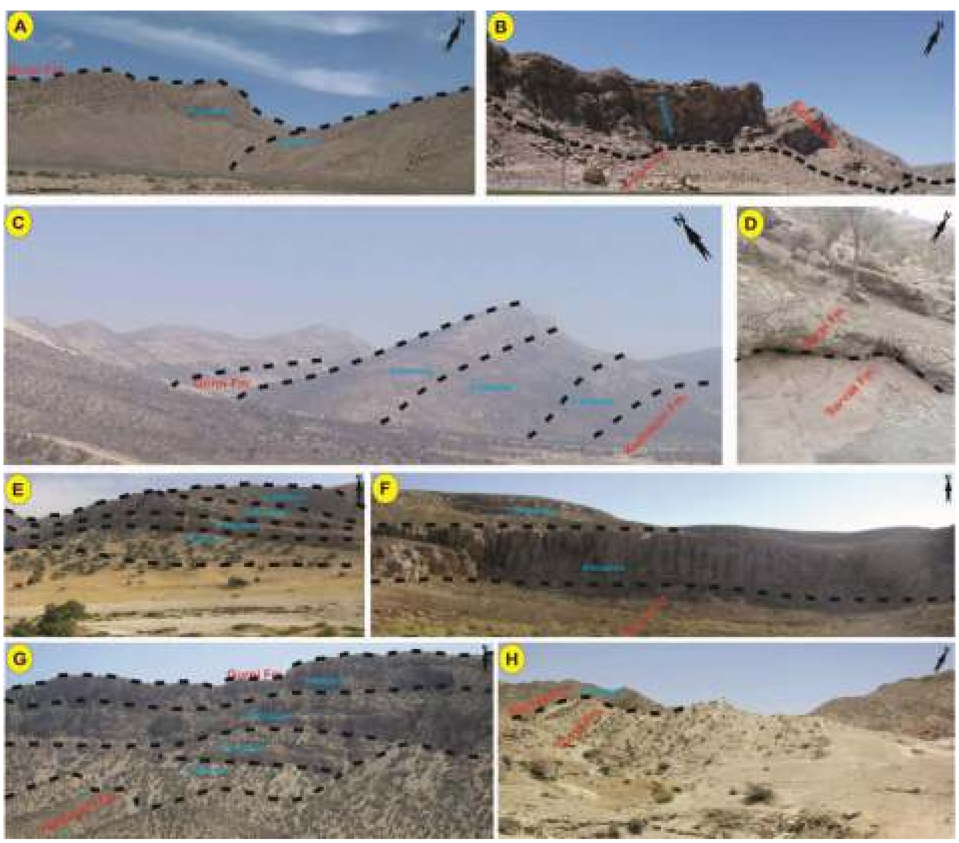

Fig. 5. Compilation of panoramic view in field photographs showing lithostratigraphy and lower and upper boundaries of the Sarvak Formation in study area. (A and B) Kuh-e- Gadvan section. (C and D) Sepidar section. (E and F) West Aghar section. (G and H) Rashtanu section.

4.2. Sepidar Section

Section Sepidar anticline also located in the interior zone. The Sarvak Formation at the Sepidar is 211 meters in thickness (Fig. 4). At the base, it is predominantly medium to thick grey to cream limestone with intercalation of thin gray limestone and with bioclast debris including Rudist, millolide, foraminifera and debris fossil. The middle part of the Sarvak Formation at this section is described by thick bedded to massive limestone. Nodular bed, bioclast debris, bivalve fragments and horizontal burrows are present. Upward, alternative of thin, medium to thick limestone are exposed. Horizontal burrow, upward thickening of beds is common. The Sarvak Formation in the Sepidar and Kuh-e-Gadvan sections transitional covered the Kazhdumi Formation accompanied by a disconformity touch and Infrastructure the Gurpi Formation (Fig. 5 A-D). The following fossils were identified in limestones of the Sarvak Formation in Sepidar section: Simplalveolina simplex – Orbitolina conica and Rudist debris range and Cisalveolina lehneri zone. Therefore, the assemblage is ascribe to the Late Albian to Middle Cenomanian based on the content of large foraminifers in this section (Figs. 3 and 4 and Table 1).

4.3. West Aghar section

Sections Rashtanu west Aghar located in the Subcoastal zone of southwest of Firuzabad town. The Sarvak Formation is between 272 (Western Agar) and 328 m (Rashtano) thick and generally contains carbonate rock and shale form units (Fig. 4 and Fig. 5. E, F, G and H). The rocks include fossil fragments, echinoderm, algae and bivalves and stylolite features are present. At the base, it is predominantly thin to thick bedded, grey and dark grey limestone. The middle unit rock of this Formation in this section is described by thick to massive bedded limestone with intercalation of dark gery, shale form. To the top in this sections remains thick to massive bed limestone are exposed. Five assemblage identified and are stratigraphic order as follows: Favuselle washitensis-Oligosteginids, Simplalveolina simplex – Orbitolina conica and Praealveolina cretacea – Nezzazata conica assemblage zone, Rudist debris range and zone. The faunal assemblage is time equivalent to number 21, 23, 24 and 25 zone of wynd (1965), indicating Late Albian-Late Cenomanian (Fig. 4 and Table 1) in age.

4.4. Rashtanu sections

The strata of the Sarvak Formation in the Rashtalu section are excellently conserved and their almost original features and thickness are attributed to minimal diagenesis, density and tectonism. The following is a summary descriptions of the lithology and stratigraphic of the study sequences summarised in the Figure 4. The Sarvak Formation in this section is subdivided into lower, middle and upper rock units based on the foraminiferal assemblages (Table 1). From top to bottom, four foraminiferal assemblages are known in this section: Simplalveolina simplex– Orbitolina conica and Praealveolina cretacea – Nezzazata conica assemblage zone, Rudist debris range and Cisalveolina lehneri zone are attributed to the Late Albian-Late Cenomanian. Based on the facies and palaeodepositional analyses arrange on the described samples a detailed biostratigraphy zonation of the outcropping section is obtained.

4.5. Facies analysis

The Sarvak Formation is divided into 12 subfacies in the studied sections, each of which is described using sedimentary structure, facies analysis, skeletal and non-skeletal components. These major facies and subfacies are described and interpreted below, and summarised on Figures 6-11 and Table 2. The paleo-environmental description of the facies is discussed in the following paragraphs.

1. Planktonic foraminifera-dominated facies

This facies (Fig. 6) typically possess a suite of planktonic foraminifera in association with oligsteginia and Hedbergella sp., Pseudochrysalidina (also include oligsteginia genera in Cenomanian strata), with the following subfacies: planktonic foraminifer's wackestone/packstone (Mf1), Shell fragments (Rudist-Echinoids) Planktonic foraminifera Wackestone-packstone (Mf2) and pelagic foraminifera Oligostegina Wackestone (Mf3) Figs. 6 A and F). This facies dominates the basinal Kazhdumi Formation and typically Rudist debris with the Planktonic foraminifer's wackestone-packstone facies at the upper rock unit of this formation in the Sepidar, West Aghar and Rashtanu sections, respectively.

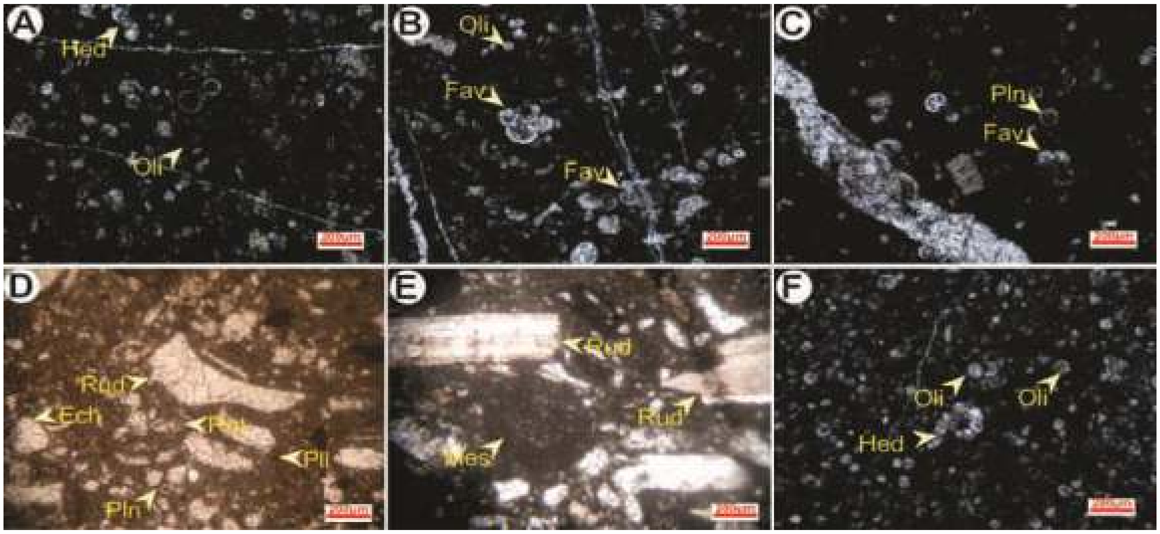

Fig. 6. Representative subfacies and fossil components of the planktonic foraminifer's facies. (A-B and C) Planktonic foraminifera – oligsteginids Wackestone with Favuselle washitensis (Fav), Oligosteginids (Oli), Hedbergella planispira (Hed), Planktonic foraminifera (Pln). (D-E) Shell fragments Planktonic foraminifera Wackestone-packstone with Orbitolina Sp. (Mes), Rotalia Sp. (Rot), Rudist (Rud), Peloied (Pll), Echnoid(Ech), plangtonic foraminifer(Pln). (F) Plagic foraminifera Oligostegina Wackestone with Oligosteginids (Oli), Hedbergella planispira (Hed) in Rahtanu section.

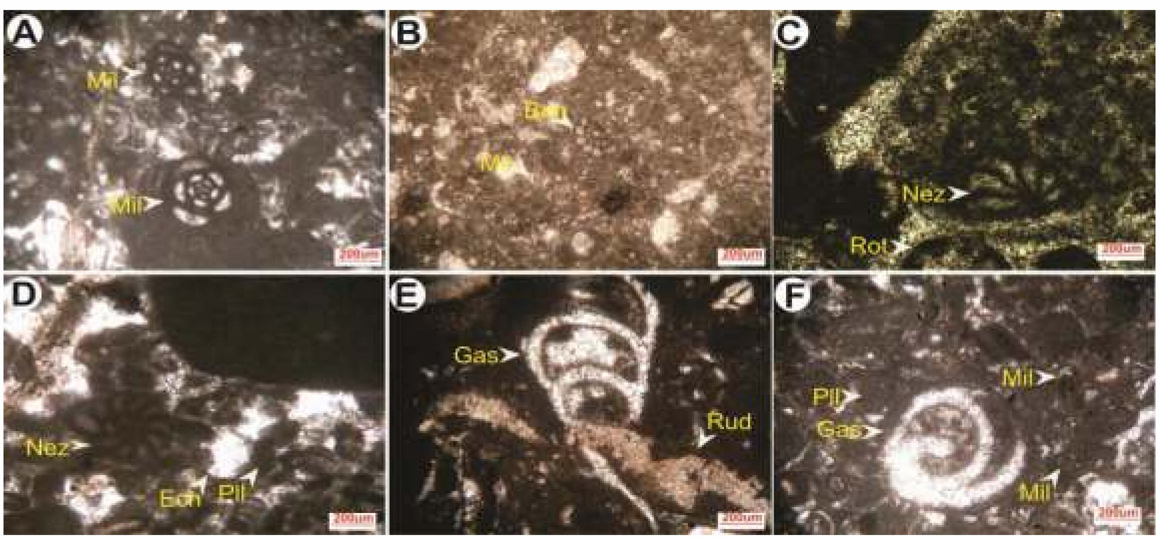

Fig. 7. Representative subfacies and fossil components of the bentic foraminifer's facies (A) Benthic Foraminifera Miliolids Bioclastic Wackestone-Packstone with miliolids (Mil) in West Aghr section. (B) Benthic Foraminifera Miliolids Bioclastic Wackestone-Packstone with miliolids (Mil) bentic foraminifer (Ben) in Rashtanu section. (C) Bioclastic Nezzazata Wackestone-Packstone with Nezzazata sp. (Nez), Rotalia sp. (Rot) in Sepidar section. (D) Bioclastic Nezzazata Wackestone-Packstone with Nezzazata sp. (Nez), (Rot), Echnoid (Ech) and Peloids(pll) in Kuh-e- Gadvan section. (E-F) Gastropod Bioclast packstone with gastropod (Gas) and debris Rudist (Rud) in sepidar section. (F) Gastropod Bioclast packstone with gastropod (Gas), Peloids (pll) and debris Miliolids (Mil) in sepidar section.

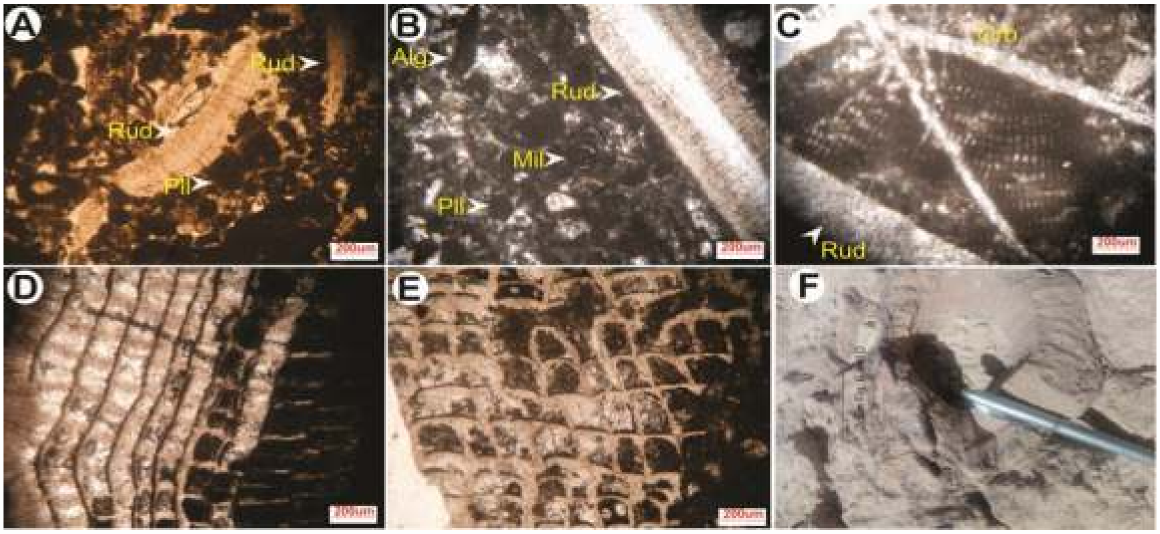

Fig. 8. Representative subfacies and fossil components of the Rudist facies (A) Bioclastic Rudist peloidal grainstone with debris Rudist (Rud), Peloids (pll) in sepidar section. (B) Bioclastic Rudist peloidal grainstone with debris Rudist (Rud), Peloids(pll), miliolids (Mil), Algae(Alg) in Kuh-e- Gadvan section. (C) Orbitolina bioclastic Rudist packstone-grainstone debris Rudist (Rud), orbitolina sp. (Orb) in West Aghar section. (D-E) Close-up view of Rudist fossil in Sepidar section. (F) Shell fragment Rudist fossil in Sepidar section.

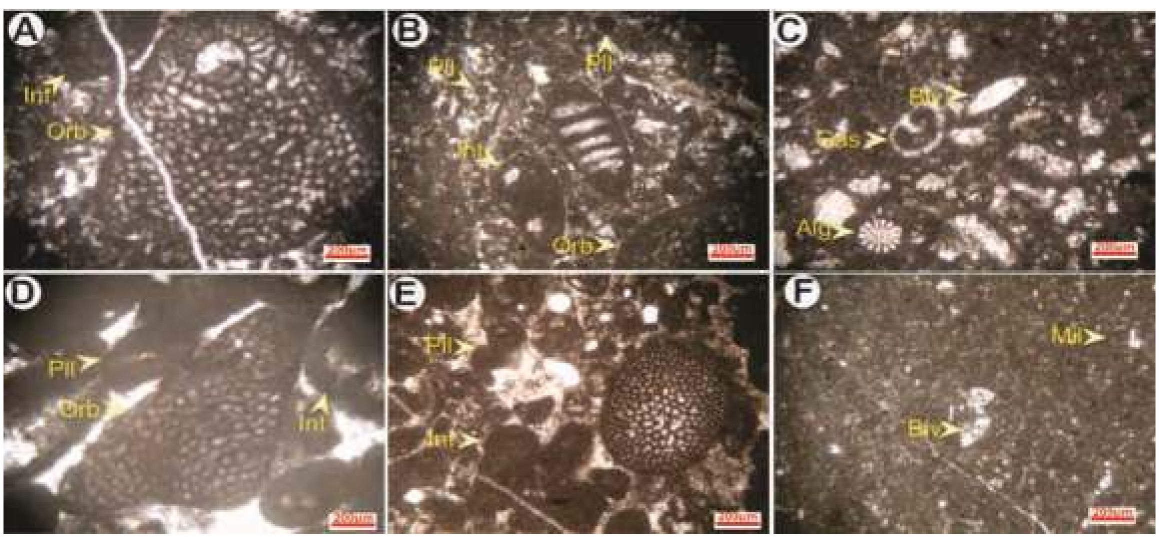

Fig. 9. Representative subfacies and fossil components of the Orbitolina and mudstone facies. (A) Intraclastic Orbitolina peloidal packstone – grainstone with orbitolina (Orb), Interclast (Int) in Kuh-e- Gadvan section. (B) Intraclastic Orbitolina peloidal packstone – grainstone with orbitolina (Orb), Interclast (Int), peloids (Pll) in Kuh-e- Rashtanu section. (C) Bioclastic peloidal green algae packstone with debris bivalves (Biv), Algae (Alg), Gastropod (Gas) in West Aghar section. (D) Bioclastic peloidal conical Conicorbitolina conica wackestone-packstone with Peloids (Pll), Orbitolinab (Orb) and interclast(Int) in Kuh-e- Gadvan. (E). Intraclastic Orbitolina peloidal packstone – grainstone with orbitolina (Orb), Interclast (Int), peloid(Pll) in Rashtanu section. (F) Argillaceous lime Mudstone/bioclastic Wackestone with debris bivalves in kuh-e- Gadvan section.

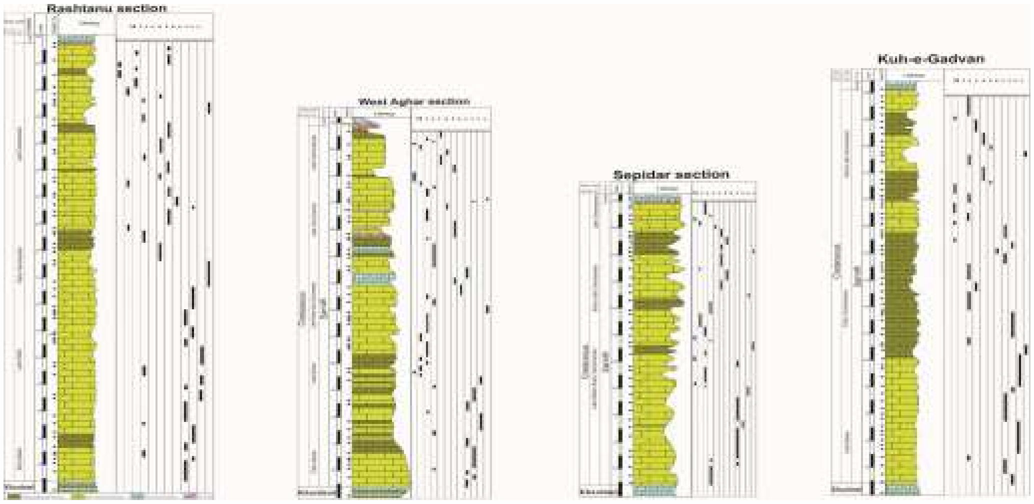

Fig. 10. Microfacies and depositional enviroment four sections of the Sarvak Formation in Fars zone.

Table 2. Facies and sub facies description and depositional environments in the Sarvak Formation in study area.

Mf1. Planktonic foraminifera – oligsteginids wackestone

Description

This subfacies, pertain to as Pelagic Sarvak Formation by Wynd (1965), includes Hedbergella sp., Oligostegina, Favusella washitensis and Rotalipora sp. This subfacies consists of thin to thick limestones described by up to 60% planktonic foraminifera associated with up to 10% debris of fine fragments (Figs. 6 A, B and C). The matrix is dominantly composed of planktonic foraminifera, occasionally rich in organic matter.

Interpretation

These subfacies are interpreted to have been deposited in a low-energy environment with a fine-grained sub succession and little carbonate impact, under a fair weather wave base in a distal presumably on middle to outer shelf settings. Deposition of Oligosteginids is typically interpreted to represent slow rates of deposition and is mostly associated with development of compacted sections (Harris & whiting 2000). Based on the above and the stratigraphic position, the Oligostegina subfacies can be attributed to the Late Albian-Early Cenomanian. The abundance of oligosteginids and non-keeled planktonic foraminifer's exhibites eutrophic conditions (Danelian et al., 2014; Romano, 2009).

Mf2. Shell fragments planktonic foraminifer's wackestone-packstone

Description

This subfacies (Figs. 6 D and E) is described by the coincident occurrence of planktonic foraminifera, debris Rudist and echinoids associated with shell fragments. This subfacies is discerned from subfacies Mf8 by the presence of Rudist-echinoids and Hedbergella sp. and orbitolina sp. which are often both abraded. In the Late Albian aged strata, especially in the West Aghar and Rashtanu section, fragments of Rudist-echinoids dominated and the name of this subfacies is changed to Shell fragments (Rudist-Echinoids) Planktonic foraminifera wackestone-packstone (Fig. 6C) and therefore will not be repeated hereafter.

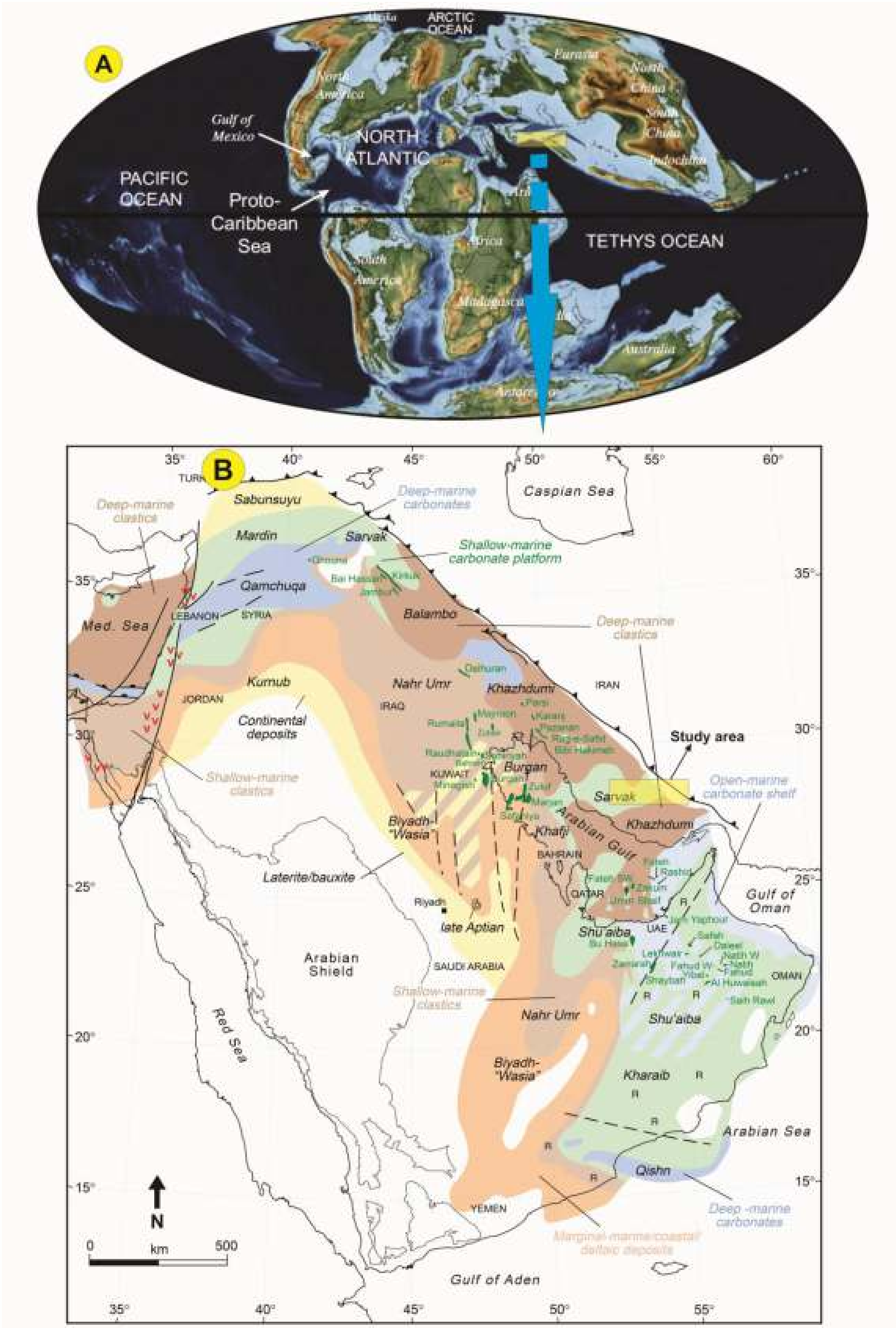

Fig. 11. (A)Paleogeographic map of world besian during the middle Cretacous (Ogg et al., 2016). (B) Paleo-tectonic map of the Arabin plate during the Cretaceous (modified from Zigler, 2001).

Interpretation

The presence of highly abraded and fragmented Planktonic foraminifera occurring in specific beds, points to occasional down-dip reworking by storms and/or bottom currents (Brandano et al. 2010). The sedimentary environment is explained as the lower unit rock of a carbonate slope. The presence of planktonic foraminifera, and photic organisms mention that this subfacies have been deposited upper the of the photic zone of a high to middle energy middle shelf setting (Gatt and Gluyas 2012). The extent of fragmentation in the foraminifer's is comparatively high.

Mf3. Pelagic foraminifera oligostegina wackestone

Description

Pelagic foraminifera make up 100% of the benthic foraminifera in this subfacies. These subfacies are delineated by a fine-grained matrix and take place in the middle rock unit of all sections. This subfacies forms medium beds, which can be easily identified in outcrops and forms a good visual marker for outcrop correlation. Larger foraminiferal (Hedbergella sp. and Oligostegina) biofabrics in this subfacies show linear accumulation, and chaotic stacking (Fig. 6F). This subfacies is most prominent in the medium rock unit of this formation and typically intercalates with planktonic foraminifera bioclastic packstone. In the Late Albian-aged strata of the West Aghar with abundance of Oligostegina, the name of this subfacies changes to Peloidal planktonic foraminifera – oligsteginids Wackestone.

Interpretation

This subfacies is interpreted to record extensive sheets of pelagic foraminifera covering the entire area seaward of the slope front. Benthic is suggestive of normal-sea situations (Geel, 2000). Besides, according to Hottinger (1997), Oligostegina inhabit the deepest paleo-environments between the observed ingredients. The joining of high rank of breaking up points to textural reversed that can be delineated by a low-energetic environment that was expose to incidental high-impact storms.

2. Benthic foraminifera-dominated facies

This facies (Fig. 7) typically possess a diverse suite of benthic foraminifera in association with algae. The proportions of certain groups of biota can vary dramatically and it is possible to identify the following subfacies that are related to slightly different depositional settings (Fig. 7).

Mf4. Benthic foraminifera miliolids bioclastic wackestone-packstone

Description

This subfacie is in all sections and is mostly composed of meter to decimeter- thick bedded limestone with benthic foraminifera miliolids. The principal characteristic of this sorted subfacies is the domination of miliolids and benthic foraminifera in a wackestone to packstone texture. This subfacies exhibit low variety and richness of miliolids, and take place at the lower to upper rock unit of the Sarvak Formation (Fig. 7 A-B).

Interpretation

The attendance of micrite texture in this subfacies exhibit that deposition was mainly in a low- to moderate energy environment. The abundance of miliolids is usually taken as evidence for restricted lagoon and/or relatively nutrient-rich back-reef environments (Geel, 2000). Hence, low variety and superabundant of miliolids exhibit that this subfacies amassed in a nourishing-rich lagoon place. This subfacies is delineated by low variety and narrow foraminifer's component. The packstone texture propose a moderate to high-energy environment.

Mf5. Bioclastic nezzazata wackestone-packstone

Description

Nezzazata constitute 30% of the benthic foraminifera in this subfacies. The additional components are rare echinoids and rotlia sp. (Fig. 7C-D). The extent of breaking up is high. show moderate percentage of sparite (Fig. 8 C-F).

Interpretation

Fragmentation exhibites high energy, however domination of micrite show that the high energy was not uninterrupted. It was apparently a lagoon in frist stage of progression, influenced by recurrent storms and deposited in an open-sea. Presence of orbitolina sp. and Rudist shows a very shallow environment (Kuss, 1992). Grain- substantiate matrix with a plentifulness of debris rudist and foraminifera, mention that a soften energy bottom flow environment happen (Lagoon toward shallow open marine). Collectively Mf8 consists of shallow water predominantly in the all part of sections and reflects a shallow open marine of the inner shelf setting.

4. Orbitolina facies

This facies arrangement comprise of medium to thick beds, grey, partly marly limestone with Orbitolina fossil wackestone-grainstone texture and packstone. The skeletal element in the matrix is abundant, slightly fractured and large in Orbitolina sp. and other fossils such as well-preserved algae, echnoids, bivalves, debris fossil and peloid. This facies (Fig. 9) consists of the following sub-facies: Intraclastic Orbitolina peloidal packstone –grainstone, Bioclastic green algae wackestone -packstone, Bioclastic peloidal conical Orbitolina wackestone-packstone.

Mf9. Intraclastic orbitolina peloidal packstone – grainstone

Description

This subfacies shape massive to thick-bedded, light grey beds settled of moderately sorted bioclasts and intraclasts that are enclosed by a sparite matrix (Fig. 9A-E). Intraclasts are usually polymodal in size, determining from 0.25 to 5 mm, with a mediatory of 3 mm. Most of the intraclasts are subangular. Some intraclasts are on the inside similar and consist of micrites, while others show on the inside constitution such as peloids and Orbitolina sp. Bioclasts of orbitolina, fragment fossil and algae are demonstrate.

Interpretation

Intraclast in grainstone and packstone texture are frequently explained as deposits shaped with the erosion of storm wave, tidal currents and the processing of various types of sediments occurring in open- marine environments (Flugel, 2010). Roundness of intraclasts and the attendance of sparite matrix show sediment deposition in high energy environments from erosion of tidal channel and erosion barriers (Tucker & Wright, 1990) that connect to the lagoonal with open marine environment.

Mf10. Bioclastic peloidal algae packstone

Description

This facies is shaped by bioclastic packstone and minor wackestones. The main contian of Mf10 are non-skeletal and skeletal components. Skeletal ingredients include fragments of green algae, echinoids and gastropod, mollusca and debris Rudist are very rare. Peloids are the predominant non-skeletal associations. This subfacies is describe by low difference and limited foraminifer's component and take place at the upper part of the all sections (Fig. 9C).

Interpretation

Subfacies Mf10 formed in a lagoon toward open-marine environment below normal sea salinity situations, with medium energy. This explanation is leaning on the stratigraphic position and frequency of open sea skeletal fauna contain green algae and debris fossils. The presence of algae and peloids propose a restricted environment, leaning on low difference. The packstone texture propose a moderate energy environ-ment. According to Flugel (2010), peloids in sparite and micrite matrix with low difference of fossils suggests this subfacies is common in shallow-sea surroundings with soften water circulation.

Mf11. Bioclastic peloidal orbitolina wackestone-packstone

Description

This subfacies be composed of grey, thin to medium bedded in the peloid bioclast wackestone to packstone. This subfacies shows low difference and high frequent of orbitolitids sp. and peloids (More peloids are constant in size (Fig. 9D) occurs at the basin and middle part of the all sections. All the grins are cemented by some generations by micrite however the texture is principally sparry calsit. Gastropod, echnoid and fragment fossils is common in this subfacies.

Interpretation

This subfacies is explained to be identified in the lagoon. In subfacies peloidal packstones, the attendance of conical-orbitolina sp. and control of peloids show deposition in a shallow lagoonal environment, low energy with poor link with the open-sea (Tomasovych, 2004) and the low diversity of debris fossils exhibit deposition in surrounded sub-tidal with low sedimentation appraise (Flugel, 2010) and these declaration and stratigraphic location, subfacies 10 was deposited in shallow-marine.

5. Mudstone facies

This facies (Fig. 9F) consists of the following sub-facies: Argillaceous lime Mudstone/bioclastic wackestone. This facies is almost lacking of bioclasts exclude for a few of debris fossils, a marked compare from the other facies.

Mf 12. Argillaceous lime mudstone/ bioclastic wackestone

Description

This subfacies is consisted of cream to grey color, thin to thick bedded limestone. These subfacies are lime mudstone with very rare fragmentary fossils. It consists mainly of microtubes and fine-grained mixers homogenous micrite and bivalves (Fig. 8F).

Interpretation

The dominant lithology of lime-mud, very rare fragment fossils, and stratigraphic location indicate that sedimentation occurred in a low-energy and shallow environment (Corda and Brandano, 2003; Sugden, 1963, 1966). Variety and size of bioclasts indicate deposition in shallow open marine setting (Spalletti et al., 2001).

5. Conceptual depositional models

The interpretation presented in this study, is based on the texture, the faunal constitution and the position along the paleo-depositional profile simultaneously with vertical and lateral facies distributions. Together, these have been used to explained the location of the different subfacies on the shelf sloping, while relating these to the relative water depth of deposition as well as replace through space and time, as seen from the facies commentary and local to the shelf depositional system (Figs. 11 and 12).The various stages include the Cretaceous (Albian) through to the Cenomanian and range from shelf top (inner shelf) through to shelf basin (outer shelf) settings (Fig. 11). However, the Sarvak Formation in the studied areas appears to be an Orbitolina-dominated shelf during the Albian (Figs. 10, 11 and 12), a Rudist-dominated carbonate shelf during the Cenomanian (Fig. 12C-D). These various stages are discussed in more detail, and according to their stratigraphic order, below.

5.1. Late Albian Favuselle washitensis - dominated shelf

The main shelf environments are briefly described in the following sections. The Mf8, Mf9, Mf10 and Mf11 facies are more common along the depositional profile from distal to proximal (Fig. 12A).

Inner shelf environment

Foraminiferal packstone/ grainstone (Mf9 and Mf10) facies, occur in a proximal inner shelf environment in the more eastern and proximal area. The shallower portions of the shelf (inner shelf), which extensively occurs in the Khu-e-Gadvan, were established by Mf9, Mf10 and Mf11 facies. This subfacies exhibit clear evidence of rework and sorting and are reasonable to have been deposited over fair weather wave-base on the inner shelf (Brandano et al., 2009) (Fig. 12A). The biogenic assemblages identified within the inner shelf facies of the Sarvak Formation during the Late Albian show a strata within the euphotic zone, in a seagrass-dominated deposition, as proposed by the attendance of Orbitolina sp., Miliolids, Gastropod, Rotalia sp., Spiroloculina cretacea, Foraminifera.

Mid-shelf environment

Orbitolina sp. and green algae facies are distinguished (Mf4, Mf10 and Mf11) by their biogenic association. These facies assemblages correspond to the middle shelf environment. Bioclastic green algae wackestone-packstone and packstones constitute one of the most abundant facies of the Late Albian successions in the West Aghar and Rastanu sections. However, during this time, the main biogenic components of the middle shelf composed of monospecific, large, robust to flat forms of Rotalia sp. which separate a protected (but not restricted) inner shelf from some more open marine settings (Corda and Brandano, 2003). Variable proportions of miliolids occur with Orbitolina sp., which implies reworking of these fossils, probably because of the influence of storm process. These foraminifera are present in high quantities in microfacies Mf4 and Mf11, which Orbitolina sp. and miliolids dominated the benthic fauna represents an uppermost middle shelf facies (Fig. 12A).

5.2. Late Albian Orbitolina conica dominated shelf

The facies model demonstrate here (Fig. 12B) display a depth of slope from shallowest part of the shelf (inner) described by Mf7 and Mf9 facies to the shallow part of the middle shelf with Bioclastic peloidal conical Orbitolina wackestone-packstone facies (Mf11 and Mf10) to a deeper middle shelf to shallower part of the outer shelf settings with Mf1, Mf2 and Mf3 (only in West Aghar section) of the Echinoid bioclast wackeston-packstone dominate facies.

Inner shelf environment

Small benthic foraminifer's facies (Mf7 and Mf9), take place in a proximal inner shelf environment in the more eastern area of the Kuh-e-Gadvan and Sepidar sections. The textural characteristics and skeletal constitution are very similar to other seagrass meadow examples (Rahimpour-Bonab et al., 2012; Rahimpour-Bonab et al., 2013; Schlagintweit and Wilmsen, 2014; Rahimnejad and Hassani, 2016). Although direct estimates of inner shelf are difficult, these inner shelf deposits should place in the euphotic zone during Late Albian, where seagrasses thrive. The abundance larger foraminifera and peloids is coherent with sedimentation in the euphotic region (Rahimpour-Bonab et al., 2012).

Mid-shelf environment

Mf10 and Mf11 subfacies are corresponds to the middle shelf environment (Fig. 12 B). The presence of algae and foraminifera such as Trocholina, conical Orbitolina exhibit these two subfacies were located in the mesophotic zone of the middle shelf (Seyrafian et al., 2011). Comparable late foraminiferal assemblages dominated by Orbitolina Sp. and green algae with moderate to high light intensity at wide depth (Bagherpour & Vaziri, 2012).

Late comparative composite assemblages dominated by Orbitolina Sp. Green algae

Outer shelf environment

The subfacies Mf1, Mf2 and Mf3 are associated in this environmental setting. The outer shelf facies mostly consists of planktonic-foraminifer mudstones and wackestones, although some benthonic forms and some bivalves fragments also occur. The absence of in situ photo-dependent biota position the outer shelf in the aphotic zone, where reduced rates of carbonate provide from the shelf (Fig. 12 A and B). The basinal facies is in West Aghar and Sepidar sections and occurs in the lowermost part of the strata described by fine grained, well-bedded and from the side uninterrupted dark limestone deposits indicated by abundance planktonic foraminifera component during Late Albian.

5.3. Early Cenomanian rudist debris - dominated shelf

During the Early Cenomanian, the southern margin of the intrusive shelf of the Sarvak Basin in the study area is largely covered by pure carbonate platforms. The following facies are more common along the inner and mid-shelf depositional settings of the platform (Fig. 12 C): Bioclastic Rudist peloidal packstone, Orbitolina bioclastic Rudist grainstone, Gastropod Bioclast packstone, Bioclastic Shell fragments Planktonic foraminifera Wackestone-packstonef acies.

Inner shelf environment

This environment of deposition is described by high-diversity benthic foraminiferal assemblages, Rudist and debris fossil, especially in the West Aghar and Sepidar sections. The foraminiferal associations were the best matched to fauna to the palaeoenvironmental situation, such as Favusella washitensis, and Rudist, light clarity and low-substrate firmness (Rahimpour-Bonab et al., 2012). The Favusella washitensis and Rudist, ascribed to the euphotic settings, at shallow depths (Ghabeishavi et al., 2009). In the shallow-water carbonate platform deposits the postion of this surface is regulated by both sedimentological observations (Van Buchem et al., 2011).

Mid-shelf environment

Basin ward of the inner shelf facies, in all sections, the seafloor was established by flat and fine Rudist debris by Rudist algae (Mf7 and mf10). During this time, the outside edges at the edge of the paleon margin of the underlying Early Cenomanian shelf continued to aggrade and started to coalesce. Larger benthic foraminifers, mainly Favusella washitensis, Hedbergell sp., were also abundant and diversified (Fig. 12C). Reef core is mainly composed of rudits colonies, thus, the reefs described by poorly made different assemblages of Rudist (Fig. 12) (Sadooni, 2005). Such a low Rudist diversity has been identified as an inclusive characteristic of the Cenomanian reefs in the Bangestan anticline (Ghabeishavi et al., 2009).

5.4. Middle-Late Cenomanian Nezazzata - dominated shelf

Matrix sediment occurs between the Rudist and foraminifera and is generally muddy with fossiliferous mudstones, wackestones or mud-dominated packstones (Mf1, Mf3 and Mf5). Based on the coarse-grained texture and frequency of Rudist it is interpreted that deposition of most of this facies occur in the mesophotic or in the euphotic zone (Sooltanian et al., 2011). This setting was alike, in light situation and low and high energy, to the middle shelf/shelf-slope environments of the Early-middle Cenomanian.

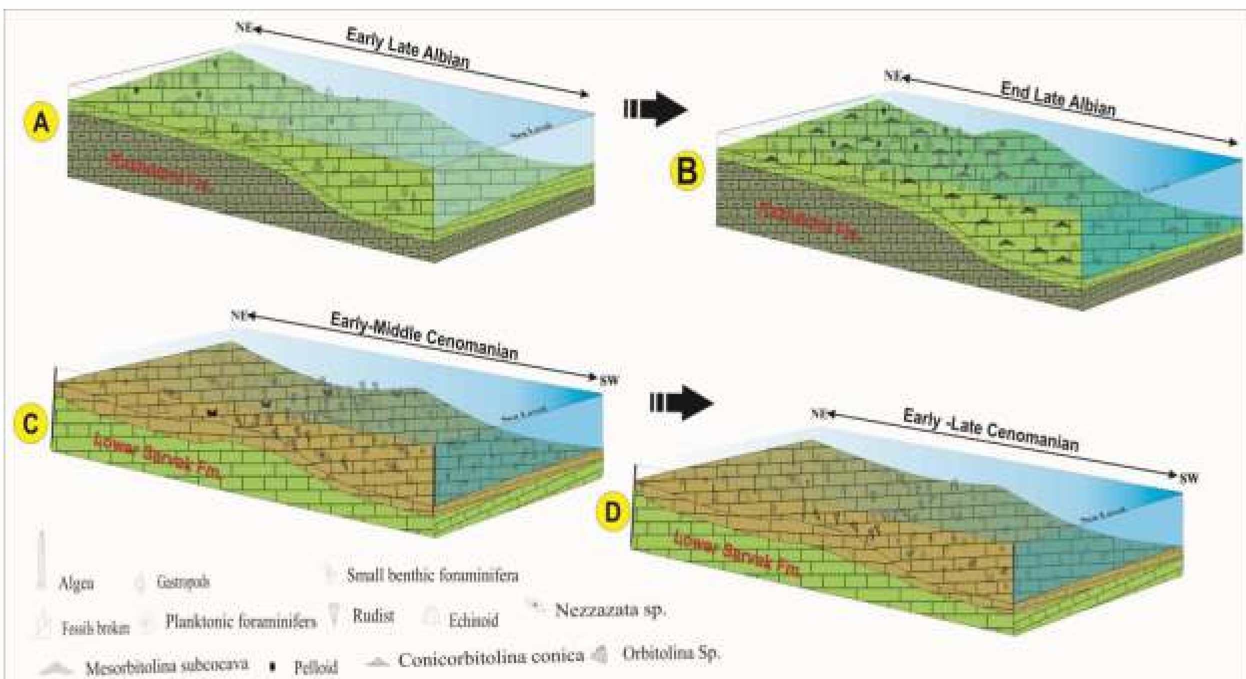

Fig. 12. Schematic depositional models of the Sarvak Formation during the (A Late Albian. (B) End Late Albian, (C) Early-Middle Cenomanian (D) Late Cenomanian with location subfacies.

Outer shelf environment

The distal shelf (middle and inner shelf) are absent and they except take place in the central intra-shelf basin (Amirshahkarami et al., 2007) and is part of the outer shelf of the Sarvak (upper part Sarvak Formation) platform. In most parts of the study area, this interval began with the deposition of deep marine deposits, indicating that the entire shelf was at least briefly in the Middle-Late Cenomanian. In this rock unit, the most common sediments in the whole region are deep-marine pelagic foraminifer's limestones with Oligosteginids and Nezazzata sp. Upward, wackestone to packstone beds are rich in planktonic foraminifera - oligsteginids (Fig. 12D). These facies in a middle shelf in a patchy distribution and usually interfere with each other (in all sections). The component derived from light-dependent biota places the outer shelf in the aphotic zone (Rahmani et al., 2009).

6. Discussion and shelf evolution

Based on literature (Ghabeishavi et al. 2009; van Buchem et al., 2011 and Asadi Mehmandosti et al. 2013; Esrafili-Dizaji et al. 2014; Vincent et al., 2015) a paleo-topography inherited from the Cretaceous influenced the Sarvak carbonate depositional in every part the Albian until the end of the Cenomanian. Therefore, the Sarvak platform, in the studied areas, starts raising on paleo-topography determined by Albian platform (Khazdumi Formation) margins inclosing an intra-shelf basin described by deep-marine marl and limestones of the Khazdumi Formation in the southern margin of this basin (Van Buchem et al. 2011). With progressive in-filling of the basin, the Sarvak platform prograde over the Khazdumi Formation such that the Sarvak/Khazdumi contact is par conformity, becoming younger basinward, while the top of the formation with Gurpi Formation generally concords to a more or less constant disconformity (Bauxite zone). Based on lower part, the lower boundary of this formation is Late Albian and Late Cenomanian in age in the Khu-e-Gadvan and Sepidar and west Aghar, whereas it was deposited in Albian-Cenomanian in the nearby Rashtanu and West Aghar outcrop. As a result, the Sarvak platform in the Rashtanu and West Aghar outcrop was situated in the more basinal position during the Late Albian than the Khu-e-Gadvan and Sepidar sections in Late Albian-Late Cenomanian. During the Albian, at the Khu-e-Gadvan, Rashtanu and west Aghar sections the Orbitolina sp. rich sediments of the lower part of the Sarvak is replaced by intercalation of limestone with marl limestone of the Khazdumi Formation. During this time, the Sarvak Formation in the studied areas appears to be an orbitolina sp and Rudist-dominated shelf with minor pelagic foraminifer. During the Cenomanian a Rudist and pelagic foraminifer - rich shelf dominated. With progressive in filling of the basin, a Rudist -dominated shelf occurred during the most of the Cenomanian especially in the Rashtanu and West Aghar outcrop and Kuh-e- Gadvan Sections. In the uppermost Late Cenomanian time, when restriction of the seaway resulted in an abrupt change to carbonate-marl facies of the Gurpi Formation.

7. Conclusions

Sarvak Formation in the Fars region of the Zagros Basin is included of very-thick bedded to massive limestone in the lower rock unit medium to thick bedded limestone in middle rock unit and medium bedded limestone in the upper rock unit. Five assemblage zones (Favuselle washitensis-Oligosteginids, Simplalveolina simplex – Orbitolina conica, Rudist debris, Cisalveolina lehneri and Praealveolina cretacea – Nezzazata conica assemblage- zone) are identified by occurrence of the foraminifera and other fossils and the Sarvak Formation at the study area is Late Albian-Late Cenomanian in age. Facies analysis allowed the identification of four main facies and twelve subfacies that parted into three depositional environments (inner, middle and outer shelf). The main facies are orbitolina sp.-dominated shelf with minor Orbitolina sp. during the Late Albian, a Trocholina sp. - commanded shelf during the Late Albian, a Rudist- to algae- commanded shelf during the most of the Early Cenomanian and a pelagic and benthic foraminifera-dominated shelf during Middle Cenomanian and mudstone facies. Environmental explanation indicate that an inner, middle, and outer part of a homoclinic shelf dominates during deposition of the Sarvak Formation in all sections. By comparing the four sections, it can be stated that the depth of the deposited basin of the Sarvak Formation was from the Kuh-e-Gadvan section to the Rashtanu section and was deposited in a longer time.

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Author's Contribution

Vahid Ahmadi developed the theory, was involved in writing and conceived the presented idea. Behzad Parnian supervised the overall project. Hamzeh Saroii supervised the findings of the project. Mohammad Bahrami was involved in writing and correlation of results and is also corresponding author

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