Microfacies, Sedimentary Environment and Sequence Stratigraphy of Gadvan and Darian Formations in the Zagros Basin, South of Semirom, Iran

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Abstract

Gadvan and Darian formations are in the upper part of Khami group that has been deposited in the highland Zagros zone and the southern Margin of Neotethys. These formations outcrop in the south of Semirom (Agh-Dagh Mountain) consist of Orbitolina limestones and marly limestones with a Late Barremian-Aptian age and thickness of 520 meters. Based on field characteristics, petrographic and texture of facies, these rocks consist of Oregonian facies (Urgonian facies) with 12 carbonate microfacies which are deposited in Lagoon, barrier and shallow open marine. The absence of loss and flows of turbidities indicates that carbonate platform of Gadvan and Darian formations in the studied area are (Hmoklinal) platform type. Abundance of rudist (bivalves) and peloid markers show that there is a Photozoan collection in tropical climates. In the above sedimentary succession, from a sequence stratigraphic perspective, three sedimentary cycles were recognized which deposited in a platform model. The Gadvan Formation overlies on Fahliyan Formation disconformable and is covered by Darian Formation gradual with reducing the amount of marl and increase of limestone. The Kazhdumi Formation is exposed disconformably with hematite nodules and oxidized sediments over the Darian Formation. On the basis of petrographic studies, diageneric process of Gadvan and Darian formations in the study area includes cementation, the physical and chemical density and replacement processes such as pyritation, ironies and silica. Porosity observed in the study area is mainly inter-granular porosity type, modular and vaggy.
Keywords
Zagros, Gadvan, Darian, Cretaceous, Sequence Stratigraphy

1. Introduction
Lower Cretaceous in the Zagros system includes marine carbonate sediments, which is mostly limestone and marl, and covers most of Zagros basin. Although carbonate and marine sediments of Jurassic are covered disconformable by Cretaceous facies, Zagros sedimentary rocks have not the same facies and same depositional environments [1]. The Gadvan and Darian formations are observed in the upper part of the Khami Group. Gadvan Formation is locally source of oil, and cap rocks for Fahlian oil reservoir and with Darian Formation make the Khami group. Its type section introduced for the first time by James and Wynd [2] at the eastern end of the Gadvan Mountain, 40 km northeast of Shiraz. The Gadvan Oregonian facies are neritic limestone with fossilized river and orbitolinide as Barremian and Aptian extensive a large part of the Tethys Ocean, the Mediterranean region and Iran to Central Asia. Limestones contain rudist, Orbitolinidae, miliolids, calcareous algae, corals, sponges, bryozoan and gastropods. The limestone facies belong to the warm sea and low depth. These formations in terms of lithostratigraphy, biostratigraphy, microfacies, sedimentary environment, paleontology and sequence stratigraphicby have been studied by others such as Wales [3], Kheradpir [4], Golestane [5], Hussein et al. [6] [7], Habibi, et al. [8], Ghalavand [9], Safari, et al. [10], Barzehgar [11], Amir Shah Karami, et al. [12], Motiei [13], Abyat [14], Sedaghat [15], Afgah, et al. [16].

2. Study Section
The study section is located in the south of Semirom (geological map of Semirom on scale 1/100,000) and the south slopes of Agh Dagh Mountain, in the Zagros folded with co-ordinates: N 31°05'08''; E 51°55'14'' (Figure 1). The Gadvan Formation (150 m) consists of thin- to medium-bedded marly limestone, marl, fossiliferous limestone and nodular limestone and the Dariyan Formation (370 m) consists of medium- to thick-bedded Orbitolina limestones (Figure 2).

3. Research Method
The best stratigraphic section of Gadvan and Darian formations in the study area has been selected and, systematic sampling was done on the basis of lithological and facies changes and in total 130 samples were collected. Microfacies were described and the depositional environment evaluated based on Wilson [17], Dunham [18], Ember and Kalavan [19], Wright [20] and Flugel [21]. To review and approve the dolomites, thin sections were stained by Alizarin Red (rd-S) and potassium ferrocyanide with method of Dickson [22].
Figure 1. (A) Showing the study area in Iran, (B) Location and access roads to the study area in south of Semirom, Zagros basin, (C) Location of studied section in geological map of Semirom (scale 1/100,000), (D) View of the Agh Dagh Mountain in southern Semirom, photo is looking to north.
3.1. Microfacies of Gadvan and Darian Formations

Based on microscopic studies and texture features 12 carbonate facies were identified at three depositional environments including the lagoon (3 microfacies), barrier (5 microfacies) and shallow open marine (4 microfacies).

3.1.1. Open marine Facies

1) Planktonic Mudstone

Allochems of this facies are very low, slightly less than 10% which includes parts of sponge spicule, planktonic foraminifera, bivalves, and gastropods. This facies are composed of micrite including existing structures in this sub-facies iron oxide concentration that are associated with stylolite. These facies were observed in thin sections 54 & 55 and dark gray color is one of the properties of the facies with abundant fractures and low fossils (sample 54). The presence of planktonic foraminifera, bivalves, and sponge spicule show decreasing energy and increasing depth. The facies was deposited in a low energy environment and calm sea [17] [21] [23]-[25].

2) Bioclast Wackestone

Allochems of this facies are very small and slight that include very small parts of siliceous sponge spicule, planktonic foraminifera, echinoids, bivalve, and gastropods. Pyrite fragments of fossil (the restoration) effect of fossils (trace fossil) for burrow. Texture of facies is composed of microcrystalline (samples 2, 10, 99, 120). The presence of
planktonic foraminifera, bivalves, sponges and thin-bedded microcrystalline show decreasing energy and increasing depth. The facies were deposited in low energy and a calm sea [17] [23] [24] [26].

3) Bivalvia Wackestone

Allochems of this facies are very low, negligible including thin of bivalves, Gastropod, radiolarian, sponge spicule and ostracods. This facies are composed of microcrystalline textures. The average gray limestone facies will see in the field by small effects of macrofossils (sample, 6). The presence of planktonic foraminifera, bivalves, and sponge spicule shows decreasing energy and increasing depth. The facies was deposited in a low energy environment and calm sea [17] [23] [24] [26].

3.1.2. Barrier Facies Belts

In the facies belts, 5 microfacies were determinate that often include a variety of benthic microfossils, interclast, Oolite, ploid, bioclast and aggregate grains that leading to packstone with grainstone rocks texture. Based on lithological composition and fossils, the belt facies, the carbonate reservoir in the inner and outer ramp was deposited between the ramps. Allochems frequency, supporter texture, tangential Oolite without Micrite, the environment is energetic [25] [27]-[30] and development this process is one of the important characteristics of carbonate shoal and carbonate ramps [31]. Microfacieses of these facies belts are as follow.

1) Peloid Grainstone

Allochems of this facies are mainly ploid with a very large percentage of small pieces of bivalves, gastropoda, algae and echinoides. Context fractures are filled by ferrous cement and asperity. The context of very small amounts of limy limestone is negligible. The text of facies is asperity and rarely iron cement and texture of greenstone are sometimes diagonal tissue stratification. According to the sorting and rounding seeds, having greenstone texture, lack of calcareous matrix, presence of haploid indicating the energetic environment such as barrier (shoal) [25].

2) Orbitolina bioclast wackestone/packstone

Allochems of this facies mainly consist of benthic microfossils such as Textularia, Natillocalina, Alveolina and Milolids, drawn and conical Orbitolina with a very large percentage of small pieces of bivalves, gastropods, and algae. Ferrous cement filled fractures context. Allochems are sporadically in parts and in some part joined. The space between Allochems is filled by mud. It is seen the color of light gray limestone facies in field for the average thickness of the layer (samples 11, 28, 29, 34, 42, 57, 95, 110, 118). The presence of Orbitolina drawn and cone-shaped shell with a small microfossils such as shell fragments, this facies indicate a shallow water conditions, light intensity, high light enough food energy and the environment barrier (shoal) [21] [32].

3) Bioclast Bivalvia packstone—Floatstone

The main allochems of this facies, including benthic foraminifera, a variety of Miliolids, along with fragments of coral, bryozoan, algae (Dacicladacea) components bivalves drawn large an amount of less than 10% are between allochems microcrystalline seen in
these facies allochems rarely have stuck together and seeds float on low density and high proportion of text micritic rock covers (samples 108, 98, 19, 13). The distinguishing feature of this sub-facies deposits are increased sorting and cementation. Bivalve’s components whose drawn large less than 10% are large stretches indicator energetic deposition conditions. So barrier microfacies have been formed above the waves effect [33].

4) Bioclast Algae Rudstone
The main constituent of this allochems for constitute of this facies, including benthic foraminifera, Miliolids types, along with fragments of coral, Miliolids, bryozoan, green algae and large drawn the amount they are above 10 percent, between allochems Hara fills sparit. Frequency of seeds in comparison with micritic context is denser. And seeds for the presence of allochems are often fossilized algae (105 samples).

The presence of the large amount of green algae and pulled them over 10% in sequence, indicating the formation of deposits in the warm sea and shallow (10 - 50 meters) offshore. Roundness sorting and abundance of grain and sparitic as dominant orthocam and lack of microcrystalline, marker high energy is microfacies. This facies is formed in a high energy represents a barrier [21] [34].

5) Orbitolina bioclast Grainstone
The main allochems for constituent of this facies, include S benthic foraminifera as a variety of Miliolids, Textularia, including parts of the Orbitolina, bivalves context fractures filled by cement, mining asparait, corals, bryozoan, green algae, between allochems Hara sparait filled seeds micritic more than text fractures filled by cement asparait hardware (example 47). Allochems that is rounded and elongated, in a cement sparait is one of the properties of energetic barrier canals [35]. In this microfacies presence of dark and thick with clams foraminifera Textularia and Miliolids also environmental conditions such as shallow, abundant food and intensity of light and energetic barrier.

3.1.3. Lagoon Facies Belts

1) Bioclast Orbitolina wackestone-packstone
Allochems the main for constitute of this facies, including benthic foraminifera as Natilocolina, Cristalidina, Orbitolina cone-shaped, Textularia, along with fragments of corals, echinoderms, Miliolids, green algae are seen between allochems microcrystalline. In these facies the seeds aren’t alongside with each other and a high proportion of text is micritic stone and low-density grains float. These facies composed of microcrystalline (sample 1, 15, 20, 27, 33, 37, 43, 59, 103, 115). Changes in shell morphology are dependant of depth and conditions of the depositional environment. The genus of Orbitolina like a shell in depth detection and differentiation is important sediment under different environments [36] facies contain Orbitolina the presence of foraminifera shells extracted more flat and the walls were distinguished. These porcelaneous in the environment with relatively high salinity light to penetrate the shallow waters of the lagoon environment are attributed [37].
2) Bioclast Algae wackestone-packstone

Allochems the main constituent of this facies, including echinoderms, Textularia, bivalves, Miliolids, drawn sickle large algae Dasycladaceae (Litocadum) facies are abundant in seeds and grains to form a dense text micritic is variable and sometimes this is taken apart denser facies have been formed (sample 4, 17, 24, 38, 45, 52, 93, 113, 124). The presence of green algae and benthic foraminifera with the mud matrix and bioturbation indicate that the facies are formed in a shallow and low-energy environment light line ray radiation is characteristic of lagoon environment [38]. Microcrystalline being formed according to the facial expression of the faces in a shallow and low-energy waves placed relatively high salinity light line [38].

3) Bioclast mudstone

Allochems of this facies is very low, which includes parts little tiny algae (Salpingopoterla), bivalves, gastropoda an important loss. This facies is composed of micrites and treatment of small diamond-that shaped funeral were formed during the process can be observed (sample 18). This facies with uniform texture of fine grained limestone and dark and pure micritic with regard to the formation of the microcrystalline and the facial expression of faces in a relaxed environment and low energy can lagoon [39] [40].

4) Orbitolina Bivalvida packstone

Allochems the main constituent of this facies include drawn Snail shape Orbitolina, Textularia, Miliolids, echinoderms, bivalves are drawn in large abundance of grain facies of the text are changeable and micritic grains used for dense texts of micrite (sample 22). This fine facies with variable knitted mud to backup seeds to the original Orbitolina micritic or wackstone to Pakstone. Allochem’s skeletal parts including ostracods, organic shells and micritic is haploid Miliolids, and field observations of moderate to thick layer of gray limestone. Place of this facies is in shallow waters and low-energy sedimentary microfacies and light this line waves lagoon depositional environment is recommended [40] (Figures 3-5).

3.2. Depositional Environment

Based on the type of micro-facies, their vertical changes, the type of skeletal components, depositional environments of the Gadvan and Darian formations in the study area include the shallow waters of the open marine, barrier and lagoon. It is worth mentioning that in the studied samples, the facies related to tidal environment were not observed. Depositional environments are specific ramp with a gentle slope to the beach area with shallow water without fracture. It is noteworthy that lead to specific domains [20] [41] to lack of turbidity facies in the study section, this type of ramp is hemoclic, because it indicates that the limy platform and slope modest increase from shallow to deep environments, such a model but of Khuzestan [42] and the Southern Persian Gulf have been identified [20] Dominant microfauna of Lower Cretaceous formations are Gadvan and Darian Orbitolina. To the size and shape of their lives Orbitolina usually epiphytic fauna is free [43] and Orbitolina internal platform in shallow waters abound with cone-shaped shell [44]. So there are genera and species of Orbitolina with
Figure 3. Microfacies of the Gadvan and Darian formations in south Semirom: (A), (B) Microfacies A1, Planktonic Mudstone (sample no. 54), (C) Microfacies, A2 bioclast wackstone (sample no. 10), (D) Microfacies, A3, bivalves wackstone (sample no. 6), (E), (F) Microfacies B1, ploid greenstone (number of sample No. 125), (G), (H) Microfacies B2 Orbitolina bioclast greenstone (samples no. 57).
Figure 4. Microfacies of the Gadvan and Darian formations in south Semirion: (A), (B) Microfacies C1 bioclastic Orbitolina wackestone-packstone (samples no. 27, 15), (C) Microfacies C2 bioclastic Algae wackestone-packstone (samples no. 17), (D), (E) Microfacies C3, bioclastic mudstone (number of samples. 18), (E), (G), (H) Microfacies C4, Orbitolina Bivalvia packstone (samples no. 22).
Figure 5. Microfacies of the Gadvan and Darian formations in south Semirom: (A), (B) Microfacies B2 *Orbitolina* bioclast wackestone-packstone (samples no. 28, 34), (C), (D) Microfacies, B4 bioclast Algae rudstone (sample no. 105), (F), (E) Microfacies B3, bioclast bioclast Bivalvida packstone - Floatstone (number of samples 108,19), (G), (H) Microfacies C1, bioclast, *Orbitolina* wackestone-packstone (samples no. 33, 59).
shelly short cone as an indication of sedimentation in the internal platform (Figure 6).

**Sequence Stratigraphy**
The sedimentary rocks of a basin are divided into sequences so that the discontinuities, and also they are separate currencies. Studied sedimentary sequences, diagnosis and vertical changes of depositional environments which depend on the relative level changes are determined seas [45]. Sequences are a part of the lowstand system tract (LST), transgressive system tract (TST), highstand systems tract (HST), and the maximum flooding surface (mfs), separated by sequence boundaries type 1 (SB1) and type 2 (SB2) respectively [46] [47]. Vertical changes of facies of Gadvan and Darian formations in the southern part of Semirom identified three sedimentary sequences type 3 with Late Barremian - Aptian age. The lower boundary sequence of Fahliyan Formation in the study area indicates a sequence boundary type 1 (SB1) and boundary between Gadvan and Darian formations is a sequence boundary type 2 as a transitional contact. The upper boundary with Kazhdumi Formation is disconformable (SB1, Figure 7).

1) **Sequence 1 (sq1)**
The first sequence with Late Barremian - Early Aptian age has 250 meters thickness. Progressive facies of this sequence are from A2, A3, B2, B3, B5, C1, C2, C3, and C4. The sedimentary system tracts includes a progressive system tract (TST), and highstand systems tract (Early and Late HST). The rule of this sedimentary sequence, layers of calcareous fossils A1 was deposited in the lagoons with discontinuous boundary of attrition (SB1) on oolitic limestone of Fahliyan Formation. Barremian sediments have deposited and Barremian calcareous fossils A1 of the time for sea-level rise progressive system tract (TST) were deposited. Changes left by sea-level rise in this system tract drowning at the maximum flooding surface (mfs), with fine balance reaches A3 facies. Facies *Orbitolina* bioclast wakstone - pakstone (B2) on the surface sinks disruption religion are blind. The sediments were deposited in shallow water lagoons and as the old system tract, highstand system tract deposits (Early HST) introduced and more facies B3, C1, C2, C3. At the end of the sequence of sedimentary facies *Orbitolina* without

![Figure 6](image_url). Gadvan and Dariyan significant sedimentary environments in Agh Dagh Mountain in the Zagros Basin, South Semirom; FWWB: The base surface waves, SWB: base of the storm.
Figure 7. Facies and sequence stratigraphy of Gadvan and Darian vertical distribution in Agh Dagh Mountain in the Zagros Basin, South Semirom.

Bivalves Pakstone (C4), This facies includes Orbitolina drawn shape, Textularia, Miliolids, echinoderms, bivalves left is drawn are large. Late in the system tract, highstand system tract deposits (Late HST) has been introduced. Finally, the second type of sequence boundary (SB2) are included (Figure 7, Figure 8). This succession is the third cycle to No. 3.5 of the water level at the time of Barremian - Aptian global shift of Haq et al. [48] in the form of (Figure 9) is equivalent.

2) Sequence 2 (sq2)

The secondary sedimentary sequences were identified in the upper part of Gadvan
and Darian formations with thickness of 180 meters. Lower boundary and upper sequence of the second type is SB2. Facies of progressive in the sequence is of A1, B2, C1, and C2. This sequence contains a transgressive system tract (TST) which is depending to former highstand system tract (Early and Late HST). Basal part of the sedimentary sequence, layers of calcareous fossils A1 that have been deposited in the lagoon with Aptian age. The A1 layer of calcareous fossils in lowstand systems tract for the duration of sea-level rise progressively (TST) has been left. Changes in sea-level rise in this system tract drowning at the maximum flooding surface (mfs), with fine facies C2 comes into equilibrium. Orbitolina facies bioclast wackstone - Pakstone. (B2) on the surface of drowning religion are blind. The sediments were deposited in the shallow waters of the

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**Figure 8.** Sequence Stratigraphy of Gadvan and Darian formations in Agh Dagh Mountain, South Semirom.
lagoon, and as the old system tract, highstand systems tract deposits (Early HST) have been introduced and then at the end of the sedimentary sequence without bivalves bioclast pakstone - flostone (B3). This facial includes a variety of Miliolids, along with fragments of coral, bryozoan, algae (Dacecladaseh) components whose are less than 10% of large bivalves are drawn, microcrystalline seen between allochems has been deposited. Late in the package, cumulative deposits (Latest) has been introduced. Finally, the second type of sequence boundary (SB 2 is included (Figure 7, Figure 8). This succession is the third cycle 4.1 Number of global change graph water level in the Aptian of sob Barremian - Aptian Haq, et al. [48] (Figure 9) is equivalent.

3) Sequence 3 (sq3)

The third sedimentary sequence has been identified in the upper part of Gadvan and Darian formations with thickness of approximately 90 meters. Lower boundary of the sequence is type 2 (SB2) and upper boundary is type I (SB1). Facies of progressive in this sequence is A2, B1, B2, B3, C1, and C2. transgressive system tract (TST), depended former highstand system tracts (Early and Late HST). Basal part of the sedimentary sequence, layers of calcareous fossils A2 that have been deposited in the marine environment with Aptian age. A2 limestone layers within the transgresive system tract increase in water level (TST). Changes left by sea-level rise in this system tract drowning at the maximum level (mfs), with fine facies C2 comes into equilibrium. Ploid grainstone facies (B1) on the surface of drowning religion are blind. The sediments were deposited in shallow water and alokames this facies deliberately ploid with a very large percentage of small fragments of bivalves, gastropods, algae Thistle ecinoderma an important loss. As a system tract, highstand system tract deposits (HST) have been introduced and at the end of the first sequence boundary (SB1) are included (Figure 7, Figure 8). This succession is the third cycle is equivalent to No. 4.1 of the water level at the time of Barremian - Aptian global shift form [48] (Figure 9).
4. Conclusion

Gadvan and Darian formations in south Semirom composed of 12 microfacies belong to open sea, lagoon and barrier. According to the fine facies distribution and field evidence such as the absence of smears reef and progress of lagoon, these formations were deposited in a carbonate shelf including three internal shelf, intermediate shelf and outer shelf. Also three sedimentary cycles of grade 3 are detected in sequences of Agh Dagh Mountain.

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