

Facies Analysis, Depositional Environment of the Lower Permian Deposits of Chili Formation in Kalmard Block, Eastern Central Iran (Darin Section)

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Abstract

Early Permian deposits in north of Kalmard region recognize with formal group of Khan; they have various features in the different place. This group includes four different formations from lower to the upper part: Chili, Sartakht and Hermez. These formations consist of carbonate rocks. Chili Formation has 104 m, thickness in Darin section and consists of limestone with intermediates of shale and marland sandstone. Lower boundary of this formation is disconformable with Gachal formation. The upper boundary is separated by unconformity from the upper part Sartakht formation according to the lithological characters and microscopic studies, cause identifications of beach, intertidal, open and semi-restricted lagoon, shoals and bar and open marine sub-environments for the Chili Formation. Vertical changes of microfacies and depth changes curve show much more thickness of shoals and bar microfacies, and little thickness of open and semi-restricted lagoon and open marine microfacies. Deposits of Chili Formation in Darin section deposited in the gentle gradient Homoclinal ramp in the south of Paleotethys Ocean. Two depositional sequences have been identified in this formation, based on recognized Fusulinid, show age of Sakmarian, which has adaptation with Lower Absaroka III.

Keywords

Kalmard Area, Chili Formation, Depositional Environment, Darinsection, Paleotethys, Sartakht, Gachal

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1. Introduction

Central Iran, shaped like a triangle and as one of the major, largest and most complex geological units in Iran, is located in the center of Iran. The dominant structural pattern of this area is of separate blocks type, separated from each other by deep faults and thus, has distinct characteristics. Kalmard block forms a small part of this area and is located between Kalmard Faults in the east and Naeni Faults in the west [1]-[3].

Chili Formation, composed of sandstone and limestone, is one of the depositional units of lower Permian in Kalmard block and one of the most perfect outcrops of Chili Formation in Darin section. Darin section has mainly consisted of limestone, sandstone.

Darin section is located in the southwestern Tabas (at 1:250000 scale) and Eastwestern Robotkhan (at 1:100000 scale) in Kalmard area (eastern central Iran). This section is framed by the geographical coordinates of 33°31'01"N and 56°09'14"E (Figure 1).

2. Materials and Methods

To detect the facies characteristics and conditions governing this sedimentary environment as well as its cycles and sequences, the field studies were carried out. To do so, one of the most complete outcrops of Chili Formation (Darin section) located in the Kalmard Block is selected.

During the experimental studies, a sample of 34 microscopic thin sections, one section for every rock sample and in some cases, to increase accuracy, two or three thin sections, were taken. These sections are determined in different directions so that two sections are perpendicular to the bedding plane and one another, and one section is parallel to the bedding plane.

Microscopic thin sections are employed to study the facies, fossils and conditions governing the sedimentary environment. Additionally, the sedimentary environment of this part of sequence is interpreted and depicted, and the studied sequence is discussed based on the existing evidence.

Dunham's (1962) classification is also used to study and nominate the carbonate rocks, in which the maximum size of matrix grains is 0.06.

This study aims to achieve the following goals:

- Exact study and analysis of the microfacies of Chili Formation in Darin section
- Reconstruction of depositional environment of Kalmard area in Sakmarian epoch (early Permian) based on in Formation on microfacies and field observations.
- Relative sea-level fluctuations curve and its relationship with the relative sea-level Fluctuations curve at global scale in early Permian.

3. Discussion

Field observations and petrographic and microscopic analyzes of the sequence represent a couple of facies groups, indicating five sedimentary sub-environments.

- 1) Beach sub-environment (microfacies A)
- 2) Intertidal sub-environment (microfacies B)
- 3) Open and semi-restricted lagoon sub-environment (microfacies C)
- 4) Shoals and Bar sub-environment (microfacies D)
- 5) Open marine sub-environment (microfacies E)

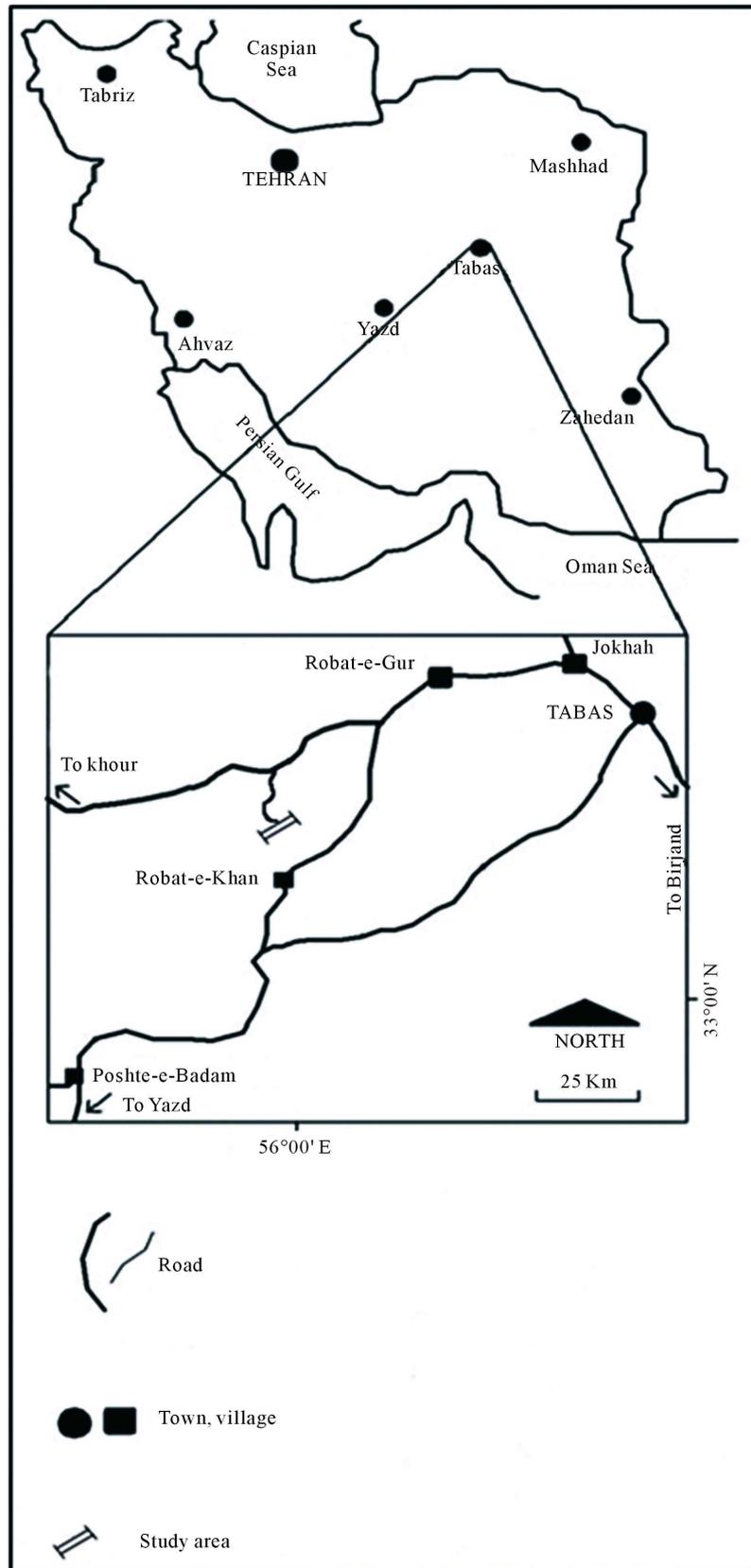
3.1. Beach Sub-Environment (Facies A) Consists of the Following Microfacies

3.1.1. A1: Horizontally Laminated Sandstone (Sh)

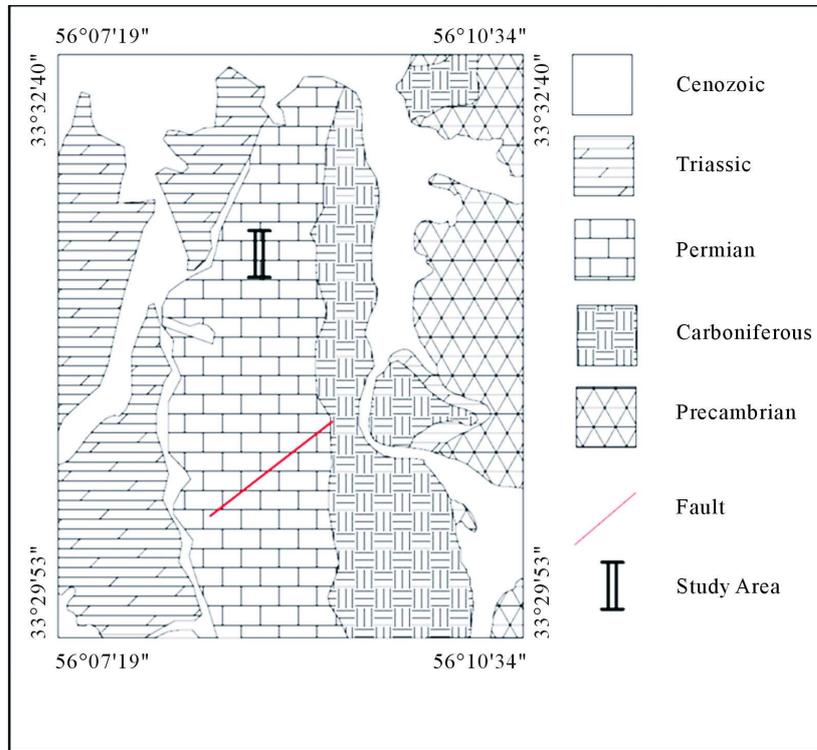
This facies consists of horizontally laminated fine-grained sandstones. This section, with 6 m thickness, is located in Darin section. This section represents semi-rounded, moderately sorted and semi-mature grains in size of 0.125 mm. These sandstones enjoy quartz arenite petrofacies (Figures 2(a)-(c)).

3.1.2. A2: Planar Cross-Bedded Sandstone (Sp)

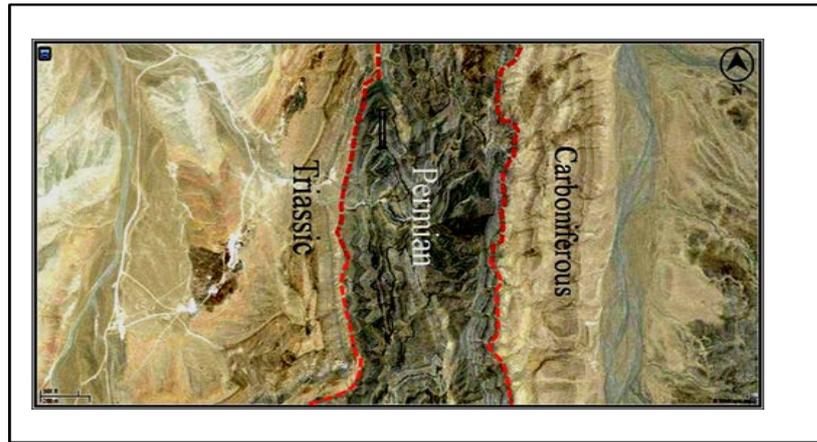
This facies contains flat diagonal classification and enjoys high frequency in the upper parts of this section. Diagonal layers have an angle between 10 to 13 degrees and can be found in either simply diagonal or mixed forms, accounting for deposits in aqueous environments with unidirectional and bidirectional flows [4]. The size



(a)



(b)



(c)

Figure 1. (a) Geographical position and access ways; (b) geological map of Chaharmahal and Bakhtiari province, Iran; (c) satellite images of the Darin section.

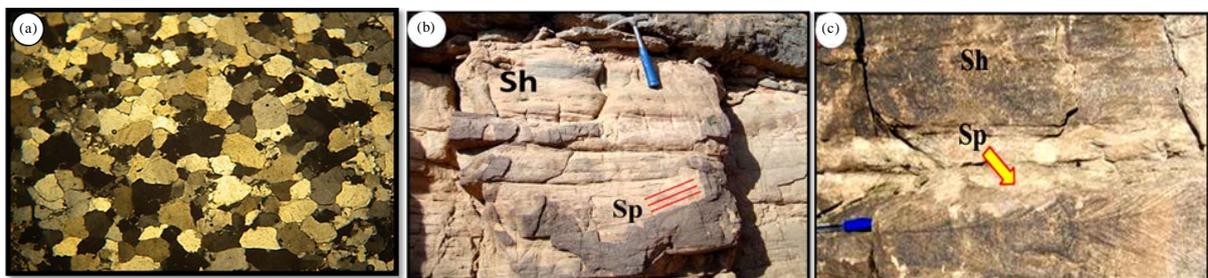


Figure 2. Microfacies of beach environment: Quartzarenite.

of grains is 0.3 to 2 mm. These sandstones comprise quartz arenite petrofacies (**Figures 2(a)-(c)**).

3.1.3. Interpretation

Sandstone facies (Sh), resulting from low and high speeds of water flow, includes flat parallel lamination as well as medium-fine grains, and is converted into other sandstone and mudstone facies [5] [6]. Regarding the grain size and the relationship between horizontal lamination and high-energy flows in fine-grain sandstones, one can attribute the formation of this facies to the high speed of water flow [7]. This facies is likely to be formed in the beach environment or in channel.

Sandstone facies (Sp) enjoys a flat diagonal classification, formed at low speed of water flow and due to the movement of ripples and two-dimensional megaripples [8]. Due to the diagonal floors, the facies Sp is developed in the intertidal zone while large-scale diagonal floors, affected by bars are formed in tidal channels [9].

Beach facies indicate relatively high energy conditions in this sub-environment. Meanwhile, the presence of the iron oxide veins can be due to the large amount of solved oxygen, proving the shallowness of this environment. Therefore, one can conclude that this microfacies belongs to a sandy beach [10] [11]. Moreover, mature petrofacies to supermature quartzarenite confirm the high tidal current regimes [12].

3.2. Intertidal Sub-Environment (Facies B) Consists of the Following Microfacies

3.2.1. B1: Mudstone with Birdseye

This microfacies is observed in grey thin-to-thick bedded limestones of Chili Formation. This microfacies mostly enjoys mudstone matrix and lacks compaction and pressure dissolution. It is noteworthy that only Bird's-eye and Fenestral fabric pores and biological disturbance are recognized there and no other allochem was found [13]. Fenestral pores are usually found in all mudstones and used to determine the amount of porosity [14]. The mentioned conditions suggest that this microfacies is deposited in the upper part of lower intertidal sub-environment (**Figure 3**).

3.2.2. Interpretation

Facies associated with upper intertidal zone are formed in dry and hot weather conditions.

Mudstone with fenestral fabric as well as biological disturbance, evaporative minerals and fenestral fabric pores suggest the deposition of microfacies in upper intertidal zone [15]. Lack of biological varieties in mudstone facies indicates lack of appropriate conditions for organisms' growth [11] [16] [17]. Due to the intermediate environment of the facies Formation, their deposits are moved out of water regularly and irregularly and show certain characteristics. These types of evaporative minerals can be found in upper tidal zone of Texas and southern coast of Mediterranean [18]-[20]. The presence of these minerals indicates a medium-heat temperature of over 22 degree C and seasonal temperature of 35 degree C [4]. These facies resemble the carbonates of southern coasts of Persian Gulf [13] [21]. Intertidal environment facies mostly involve fenestral fabric and micro foraminifera [22].

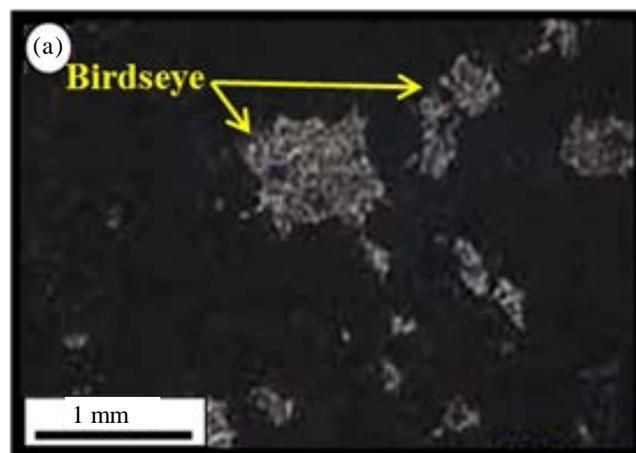


Figure 3. Intertidal sub-environment microfacies: a—mudstone with birdseye.

3.3. Open to Semi-Restricted Lagoon Sub-Environment (Facies C) Consists of the Following Microfacies

3.3.1. C1: Pelloid Pelecypoda Wackestone/Packstone

The most important and frequent allochem of this microfacies is pelecypoda (40%) with size of 1 mm. Also, the pellet found in these samples (15% - 25%) enjoys good sorting and roundness with size of 0.1 mm and is located in micrite ground. This microfacies belongs to dark grey thick bedded limestones (Figure 4(a)).

3.3.2. C2: Pelloid Intraclastic Wackestone/Packstone

In this microfacies, intraclast (35%) has weak sorting but good roundness with size of 2 mm. Also, the pellet found in these samples (10%) enjoys weak sorting and semi-roundness with size of 0.1 mm. This microfacies is located in dark grey thin bedded limestones (Figure 4(b)).

3.3.3. C3: Bioclastic Staffellidae Grainstone

Benthic foraminifer observed in this microfacies accounts for 60% of total samples and is of *Globivalvulina*-*Staffellida* type. Its grain size is 0.7 mm and enjoys weak sorting and roundness. The conditions in this microfacies are similar to those in microfacies C2 and are formed in the same environmental conditions, except that the Formation environment of microfacies C3 includes more energy. It is formed in limestones with grey shale and marl layers (Figure 4(c)).

3.3.4. C4: Bioclastic Benthic Foraminifera Pelloidal Packstone

This facies, consisting of skeletal particles such as benthic foraminifera which includes (*Globivalvulina*, *Tuberitina*, *Earlindia*. sp.), indicate 10% frequency and have the size of 0.2 mm. And pellet (35%) enjoys weak sorting and semi-roundness and its grains size is 0.1 mm. This microfacies can be found in grain thin-bedded nodular limestones and suggests a semi-restricted lagoon environment (Figure 4(d)).

3.3.5. C5: Echinoderm Intraclastic Gastropoda Packstone/Grainstone

This microfacies contains gastropoda particles (35%) and its size is 2 mm. Moreover, 20% intraclast and 5% echinoderm with weak sorting and roundness, and size of 0.3 mm are also observed in this microfacies. It is formed in limestones with grey shale and marl layers (Figure 4(e)).

3.3.6. C6: Bioclastic Fusulinid Wackestone/Packstone

This microfacies involve 45% spindle-shaped fusulinid in 3 mm size and 7% benthic foraminifera (of *Dekerella*

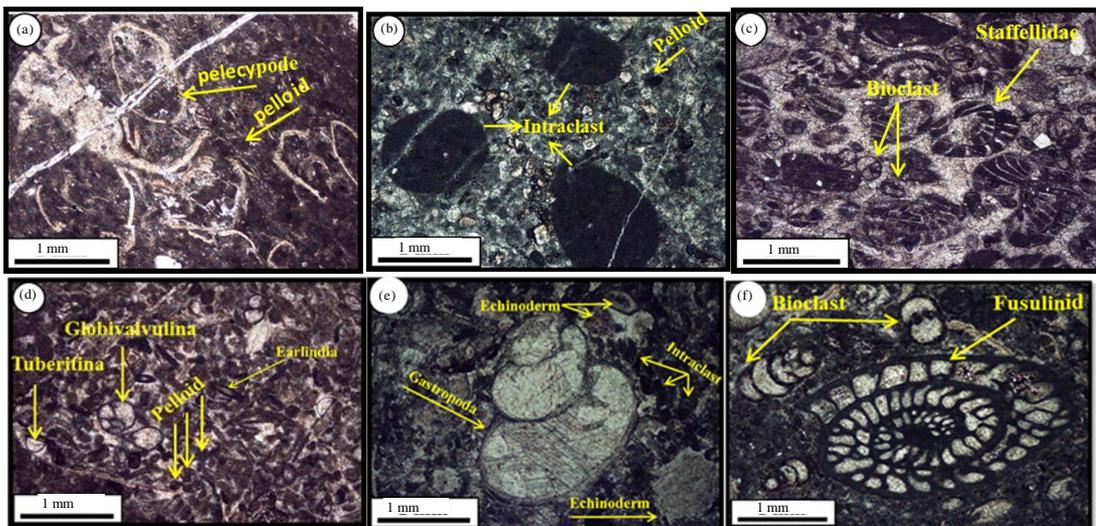


Figure 4. Open to semi-restricted lagoon microfacies. (a) Pelloid, pelecypod wackestone/packstone; (b) pelloid Intraclastic packstone/wackestone; (c) bioclastic benthic foraminifera staffellid grainstone; (d) bioclastic benthic foraminifera, pelloidal packstone; (e) echinoderm, intraclastic, gastropoda grainstone/packstone; (f) bioclastic fusulinid wackestone/packstone.

type) with weak sorting. This microfacies is formed in grey thin-bedded limestones (**Figure 4(f)**).

3.3.7. Interpretation

Some common characteristics among the microfacies of this group are the presence of lime between main grains and the presence of bioclasts, resulted from lagoon organisms, capable of living in a restricted or semi-restricted condition. The first common characteristic is a cause of tranquility in their Formation environment but the second one indicates high salinity in depositional environment of this group. The difference between microfacies of this group is due to the fabric type and their grain size [11].

Small and large algae and foraminifers are observed in facies of euphotic zone, where the water depth and nutrients are low [23]-[25].

Wackstone/packstone facies including foraminifera are formed in lagoon environment and foraminifera with porous wall are also formed in hypersaline environment [11] [17] [26] [27]. Another salient characteristic of this facies is biological disturbance, resulted from activity of infauna and points to the deposition of microfacies in a relatively calm environment with restricted water circulation and below the wave effect line. These microfacies are formed in shallower parts of lagoon under the low ambient conditions [4] [17]. The presence of microsteolites in this facies is due to lack of primary cementation, resulted from organisms' activities [28]. These microfacies are formed in the deeper parts of lagoon under a low ambient condition. Since nutrients are limited in such conditions, sediment eaters' activities rise and activities of various burrows including distinct and indistinct ones are resulted from activities of such organisms [29]. Such organisms mostly continue their life through grazing [30]. The fundamental characteristic of some lagoon facies is high percentage of pelloid, gastropoda, benthic foraminifera and intraclastics. Other elements including pelecypoda are also found in this facies, the presence of pelloid and gastropoda point to the Formation of this facies in shallower part of lagoon environment.

3.4. Shoals and Bar Sub-Environment (Facies D) Consists of the Following Microfacies

3.4.1. D1: Echinoderm Grainstone

The most important allochem of this microfacies consists of echinoderm particles (50% - 60%) and is more frequent than other fossil fragments and its size ranges from 1 to 2 mm. Echinoderm fragments are placed in sparite cement ground and enjoys microstilolite in their contact level. This facies belongs to thick bedded limestones with grey marl layers. These conditions reveal that this facies is formed in an environment with high energy (**Figure 5(a)**).

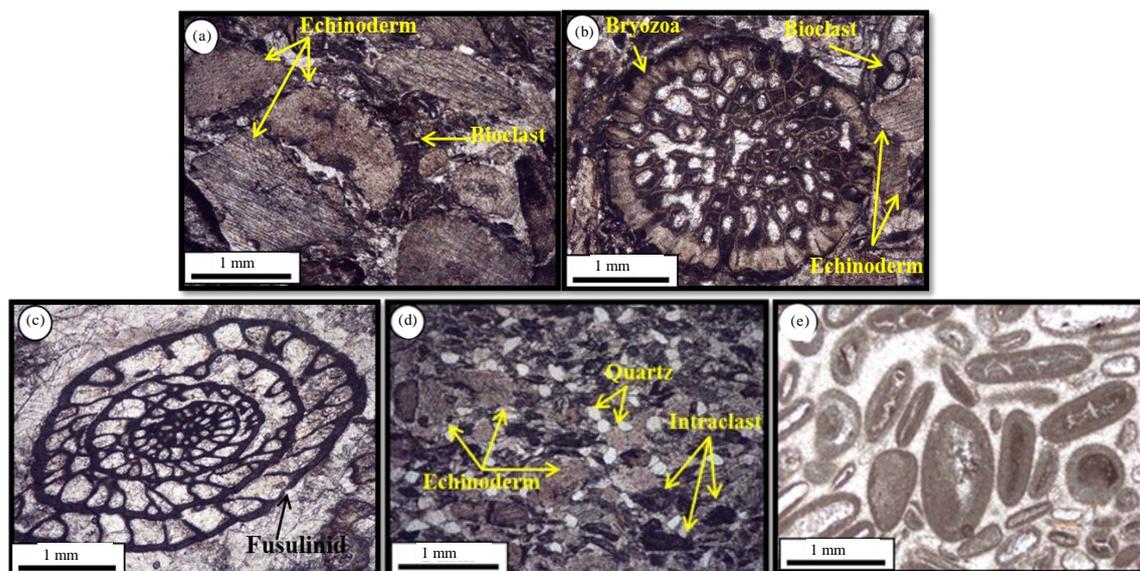


Figure 5. Shoal and Barmicrofacies (ppl), (a) echinoderm grainstone; (b) bioclastic, echinoderm bryozoa grainstone; (c) fusulinid grainstone; (d) sandy intraclastic echinoderm grainstone; (e) fusulinid oncoloidal grainstone; (f) coated bioclastic ooid grainstone.

3.4.2. D2: Bioclastic Echinoderm Bryozoa Grainstone

The allochems of this microfacies are of bryozoan type (70%) and highly rounded. Its size is 3 mm. Moreover, 5% echinoderm, 2% Ecinid, 2% benthic foraminifera, are seen there, among which benthic foraminifera contains Golobivalvulina. This facies belongs to thick bedded limestones with grey marl layers (**Figure 5(b)**).

3.4.3. D3: Fusulinid Grainstone

This microfacies, consisted of low Permian pesodufusulinid, covers 80% of the facies and its size is 5 mm. This facies belongs to grey mid-to-thick bedded nodular limestones (**Figure 5(c)**).

3.4.4. D4: Sandy Intraclastic Echinoderm Grainstone

This facies contains 30% echinoderm with 0.5 mm size, 15% intraclast with 0.2 mm size and rounded and sorted quartz in sand size. This facies belongs to grey thin-to-mid bedded limestones (**Figure 5(d)**).

3.4.5. D5: Coated Bioclastic Ooid Grainstone

This facies is covered by 40% ooid, 10% pellet and 5% bryozoa. The core of ooid is made of echinoderm, bryozoan and benthic fram. Moreover, the presence of twin elliptical ooids and lumps (some ooids in one) is of great importance. In this microfacies, due to the high-energy conditions, the ooid fragments are mostly spherical and elliptical and poorly sorted. This microfacies is mostly made of ooids of 0.2 - 0.5 mm. This facies is formed in a shoal submarine ridge due to the presence of ooids, crenoids rounded in the sparite ground and sorting of allochem. It belongs to dark grey and brown thin-bedded sandy limestones (**Figure 5(e)**).

3.4.6. Interpretation

The common characteristics of all bar facies is the lack of lime matrix among bar facies grains. This refers to the high rate of energy in their Formation environment. In other words, these facies are formed above wave effect line.

Ooid, bioclast and shoal bars facies are developed in platform margin sub-environment. Skeletal particles of organisms such as bryozoa and echinoderm are observed in slope zone and can lead to development of washed sand deposits in shoal and bars [11] [31]. This sub-environment separates lagoon sub-environment from open sea. The presence of sparite cement, ooids abundance, mid-to-well sorting and lack of lime in facies confirm an environment with high energy. Today, the same facies can be found in southern coasts of Persian Gulf and Bahamas at the depth of less than 5 m.

Ooids abundance and lack of mud matrix indicate high energy in depositional environment, in which waves and currents transfer the carbonates. Such depositions point to washed sand forming carbonate bars. The skeletal particles forming these sands are usually originated from open sea [11].

Lack of micrite is the main cause of high energy in theses facies. Large size of these particles and their relative sorting are among factors determining high energy in this facies. In addition, small amount of Isopachous cement implies high deposit accumulation rate [32]. Lack of gravity cement is a sign of not moving out of water [11] [33]. One of the characteristics of some microfacies is the presence of oncoide, accounting for higher rate of energy in the environment than that of other facies.

3.5. Open Marine Sub-Environment (Facies E) Consists of the Following Microfacies

3.5.1. E1: Mudstone

This microfacies, involving muddy ground and lacking allochem, indicate a relatively high depth during the deposition in this microfacies. This microfacies is formed in grey mid-to-thin bedded nodular limestones (**Figure 6(a)**).

3.5.2. E2: Spiculitic Radiolaria Wackestone

15% spiculite and 10% radiolaria in 0.1 - 0.2 mm are found in this microfacies. Spiculite is dispersed and no particular orientation is seen, and is mostly single-axis. Spiculite together with radiolarian in amuddy ground are among the most important components of deep and low-energy environment of open sea (**Figure 6(b)**).

3.5.3. E3: Echinoderm Fusulinid Packestone

30% fusulinid of 1 - 2 mm size and 10% echinoderm of 1 mm are observed in this microfacies. A small amount



Figure 6. Open marine microfacies: (a) mudstone; (b) spiculitic radiolaria wackstone; (c) echinoderm fusulinid packstone.

of pleoid and intraclast is seen as well. This microfacies belongs to grey thin-bedded limestones (**Figure 6(c)**).

3.5.4. Interpretation

The presence of intergranular muddy matrix [1], the abundance of spiculitic and radiolarian [17], as well as the presence of echinoderm [11], point to the formation of sediments in a low-energy and calm environment like open marine [11] [17] [34]. Regarding the presence of stenohaline species such as echinoderm, these microfacies are formed in a moderately saline environment like open marine [17] [35].

3.6. Frequency Column of Microscopic Facies

Microscopic facies are divided into two groups of orthochem including ground and cement, and allochem including skeletal and non-skeletal elements. The frequency percentage of orthochem is computed by polarized microscope and depicted separately for each allochem (**Figure 7**).

The fluctuation curve of sea level is also depicted based on vertical changes in the characteristics of microscopic facies (**Figure 8**).

3.7. Depositional Environment Model of Chili Formation Deposits

According to the results of microscopic and field observations, vertical relationship among facies and comparison between facies of Chili Formation with other depositional facies, the depositional model of Chili Formation is presented as follow (**Figure 9**). This model presents the Formation system of carbonate facies in the mentioned section under five depositional sub-environments including beach, intratidal, lagoon, shoal and bar and open marine. The sandstone deposits in the sequence are related to beach environment. These facies are formed in a low-angle homoclinal carbonate ramp [4] [26] [34] and located in the passive margin of southern paleotetis ocean [36]. Studying facies and depositional environment of Chili Formation indicate that a shallow to relatively deep marine environment is seen in the early Permian and the studied section, where various facies of Chili Formation can be found in its sub-environments. In the proposed model, beach sub-environment, referring to the moderate weather of the environment, is a place for sandstone deposits Formation. On the other hand, phenomena such as fenestral fabric are common in intertidal sub-environment, accounting for leaving water for a short time and hot and dry climate condition. Lagoon sub-environment deposits are left in an open to semi-restricted environment and separated from open marine sub-environment by organisms contributing to the bar Formation. Tidal channel sub-environment is responsible for connecting lagoon sub-environment to open marine sub-environment. Open marine sub-environment is detected through radiolaria, calcispher and spiculitic and enjoys less thickness than other sub-environments.

4. Conclusions

Having studied the facies and depositional environment of Chili Formation rocks in Darin section, the present study presents offers the following results:

- The thickness of Chili Formation varies from north to south (46 - 125 m). This thickness was 104 m in the sampling area.
- Regarding the carbonate content of the rocks of this Formation and remarkable destructive deposits (sandstone of unit 1), Chili Formation deposits are formed in a moderate and close to supply source of destructive

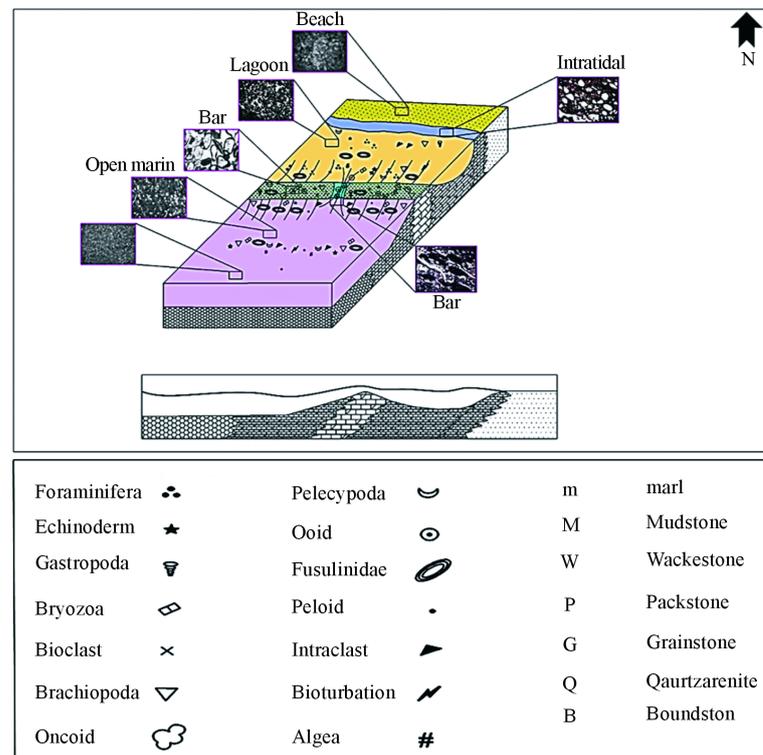


Figure 9. Depositional environment model of Chili Formation in Darin section.

deposits.

- According to the microscopic studies and field observations, the facies of this section are formed in five depositional sub-environments including beach, intertidal, open to semi-restricted lagoon, shoal and bar and open marine sub-environments.
- Vertical and lateral changes of facies and comparing them with old depositional environments reveal that the mentioned deposits are deposited on a low-angle homoclinal carbonate ramp, placed on the passive margin of southern paleotetis ocean.
- According to the microscopic studies, field observations and Sequence Stratigraphy examinations, Chili Formation enjoys second depositional sequences and many other high frequency cycles. These sequences are equivalent to the upper part of lower Absarokai great cycle and are compatible with and similar to the proposed sequences for other parts of the world.

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