International Journal of Geology, Earth & Environmental Sciences ISSN: 2277-2081 (Online)
An Online International Journal Available at http://www.cibtech.org/jgee.htm
2013 Vol.3 (3) September-December, pp.113-125/Mansour et al.

Research Article

MICROFACIES ANALYSIS AND PALEOENVIRONMENTAL RECONSTRUCTION OF THE BAHRAM FORMATION OF THE SARDAR ANTICLINE, SE IRAN

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ABSTRACT

The Bahram Formation (Middle to Late Devonian) is a Lithostratigraphic unit of the Central Iran and consists of a thick sequence of shallow-water mixed carbonates and siliciclastic deposits. This paper focuses on the microfacies analysis and sedimentary environments of the Bahram Formation. In order to study the Bahram Formation Sardar section in NE of Chatroud City, north of Kerman, in SE Central Iran has been selected. Based on filed study and petrographic analysis of thin sections 18 facies have been identified. These facies were deposited in 5 major depositional facies belts including shore face, tidal flat, lagoon, bioclastic shoal, and proximal open marine environments. Based on the gradual changes of microfacies, the lack of great barrier reefs and lack of calciturbidite it can be concluded that the sequence has been deposited on a homoclinal ramp platform with mixed carbonate –siliciclastic deposits.

Key Words: *Bahram Formation, Microfacies, Depositional Environments, Late Devonian*

INTRODUCTION

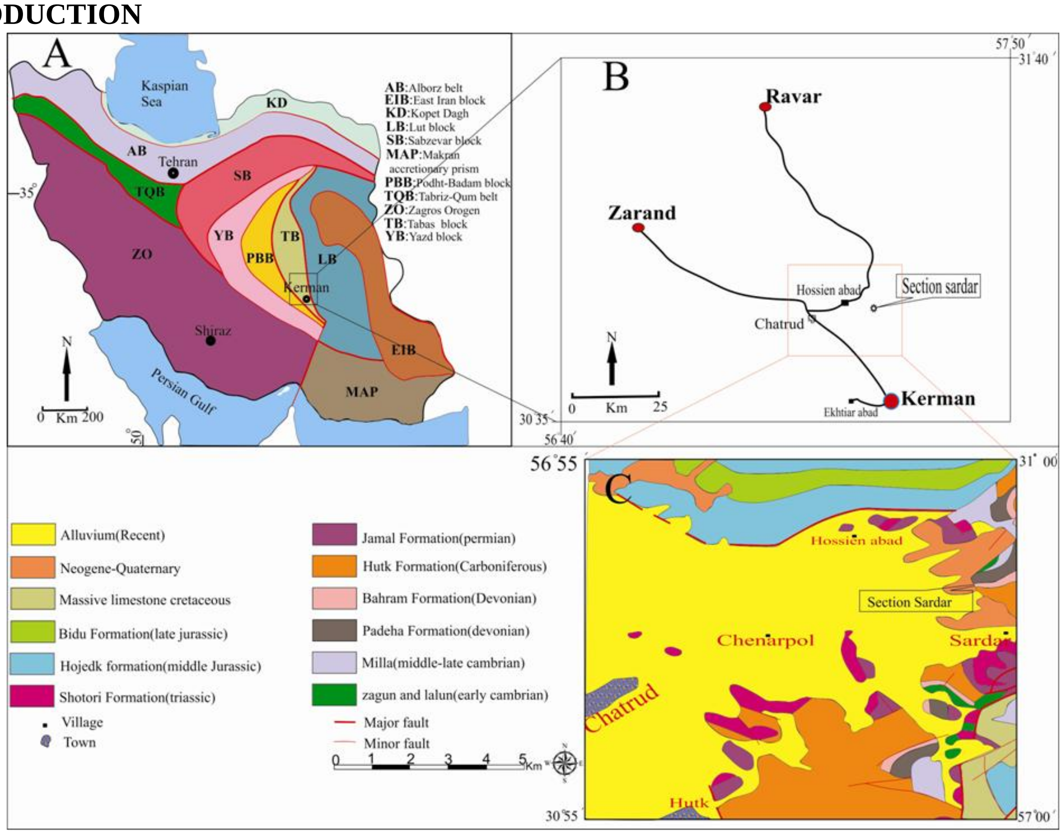

Figure 1: A: Location map of the study area in central Iran in Tabas block (Alavi, 1991).
B: Ways to access the studied area. C: Geological map the studied area

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Bahram Formation as a thick carbonate sequence of the Middle Late to Middle Devonian is present throughout the Central Iran Basin and is developed in the Kerman area as well (Figure 1). Lithologically, this formation is characterized by limestones, dolomitic limestones, argillaceous limestones, shale and sandstone Gholamalian and Kebriaei (2008) (Figure 2).

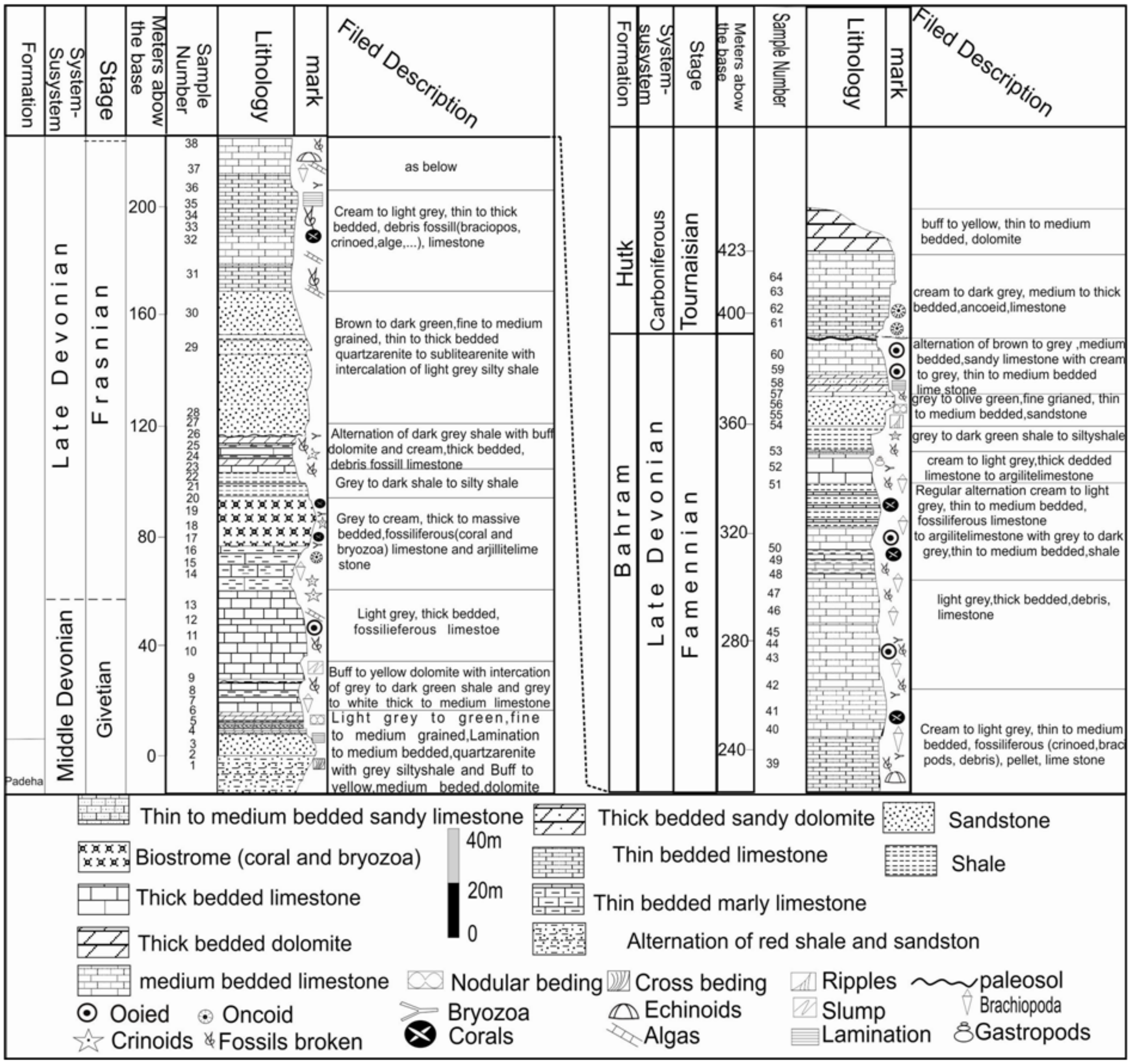

Figure 2: Lithostratigraphic column of the Bahram Formation in the Sardar Section

The Bahram Formation was originally defined in preliminary works by Ruttner *et al.,* (1965), Flugel and Ruttner (1962), Stoecklin (1972), Stoecklin and Setudehnia (1991), Berberian and King (1981), Dastanpour and Aftabi (2002), Morzadec *et al.,* (2002), Webster *et al.,* (2003), Went *et al.,* (2002, 2005), and Gholamalian *et al.,* (2009). In order to complementary study of this formation, a surface section (Sardar Section) has been selected. The section is located about 15 km northeast of Chatroud and 45 km north of Kerman with 30˚38′7.90″ N and 56˚59′53.81″E (Figure 1). This paper reports on sedimentological studies of Bahram Formation, which the results could contribute to a better understanding of the surface outcrops of the Bahram Formation in Kerman and adjacent areas. The main objectives of this research are focused on a description of the facies and their distribution on the Middle Late to Devonian carbonate platform and palaeo environmental reconstruction of the carbonate platform.

Stratigraphy

Bahram Formation is a part of Ozbak-Kuh Group and its type section is located is the south of Ozbak-Kuh. This formation has been divided into two parts, Bahram 1 with the age of Givetian to Frasnian and Bahram 2 with the age of Frasnian. These two parts are distinguishable in Ozbak-Kuh and Shirgesht area and cannot be distinguished in other parts of Central Iran. The thickness of the formation in the Sardar section is 386 m (Figure 2). The lower contact with the Padeha Formation (Figure 3) is continuous and the upper contact with the informal Hutk (Figure 4) is erosional unconformity.

Figure 3: The lower contact of the Bahram Formation with Padeha Formation

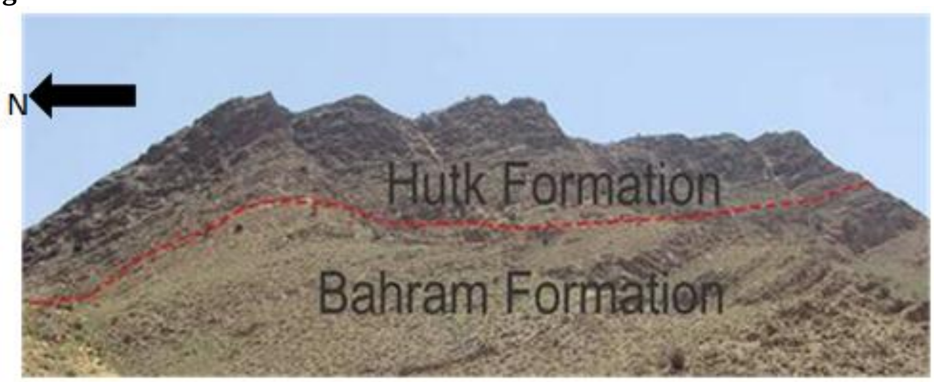

Figure 4: The upper contact of the Bahram Formation with Hutk Formation

MATERIALS AND METHODS

In order to investigate the Bahram Formation, Sardar section in NE of Kerman has been selected. The upper and lower boundaries of the formation have been identified. Systematic sampling as well as simultaneous photography of textures and sedimentary structures has been carried out. More than 64 this sections have been prepared from collected samples and studied by polarized microscope. Field observation and petrographic studies were used for facies analysis and paleoenvironmental reconstruction. Facies were determined according to carbonate grain types, textures. Carbonate and clastic facies were described according to Dunham (1962) and Pettijohn *et al.*, (1987) classification respectively. Based on Walter's law and vertical change of facies and comparison to standard microfacies of Wilson (1975) and Flugel (2010), 3D depositional model for Bahram Formation has been illustrated.

Microfacies Analysis

Based on the field study and petrographical analysis of thin sections clastic and carbonate facies have been identified. These facies have been deposited in 5 facies belt which described below.

Clastic Facies

Shore (A, B)

A1. Quartz arenite: This facies are mainly composed of subrounded to rounded, very well to well sorted fine to medium sand size grains of quartz (95-97%). Most of the quartz grains are monocrystalline with straight extinction. Feldespatic grains (2%) and rock fragments (1%) are also present. Calcite cement have been filled the pore space (Figure 5A).

Interpretation: The characteristics of this facies such as subrounded to rounded quartz grains, well sorting silicate grains with grain-dominated texture suggests deposition in environments varying from low-intertidal to supratidal (Pettijohn *et al.*, 1987).

A2. Sublitharenite: This facies is consists of subrounded to subangular quartz grains (~85%), chert (~5%) and limestone a rock fragment (~8%). Most of the quartz grains are monocrystalline with straight extinction. Sandstone, locally showing a fenestral fabric consisting calcite cement. Carbonate and dolomite are present as cements in this facies (Figure 5B).

A3. Calcareous Sandstone

This microfacies is observed in the lower part of the section. It is consists of very fine to coarse grained calstic quartz (30-45%), limestone and dolosotone, and other rock fragments (8%), and matrix (12%). Most of the quartz gains are rounded to subangular and monocrystalline to polycrystalline with straight extinction (Figure 5C).

B1. Shale

This facies observed in gray to black in most intervals and are soft and without fossil contents. Shale layers show thickness of less than 1 m and are intercalated with carbonates and sandstones (Figure 5D). Fine quartz grains are abundant (<10%) in some parts and formed silty shale.

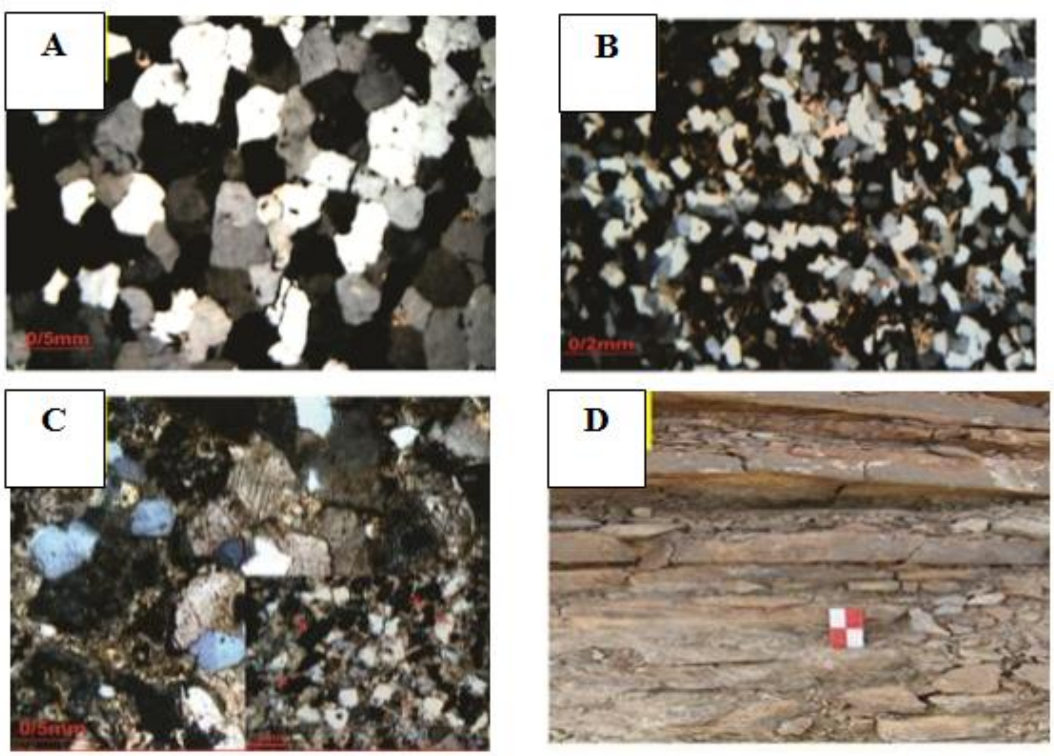

Figure 5: Photomicrograph of different facies. A: Quartz arenite, XPL. B: Sublitarenite, XPL. C: Calcareous sandstone, XPL. D: Intercalation of Shale and sandstone.

Carbonate Microfacies

Tidal Flat Facies Belt (C)

C1. Dolostone: Field exposure of this microfacies is hard, dense, yellow to cream dolomite. Those are intercalated with other carbonate facies, shale and sandstone. This microfacies is composed of euhedral to subhedral, fine grained crystals of dolomite. In some samples, subordinate amount of detrital quartz grains are also present (Figure 6A).

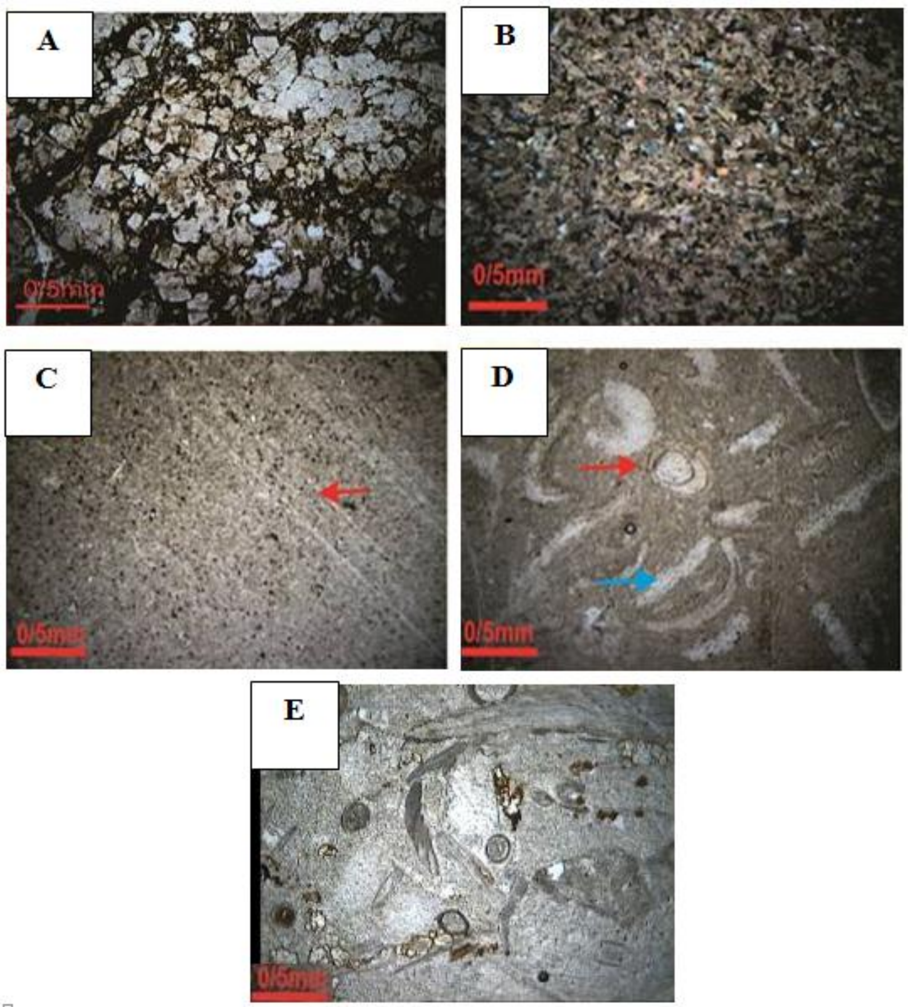

Figure 6: Photomicrographs of microfacies. A: Dolostone, PPL. B: Dolomitized lime mudstone, XPL. C: Crystalline lime mudstone, PPL. D: Bioclast wackestone, PPL. E: Bioclast intraclast wackestone to packstone, PPL.

Interpretation: Based on the presence of primary dolomite and clastic grains, it can be concluded that the facies was deposited in intertidal environment (Wilson, 1975; Flugel, 2010).

C2. Dolomitized Lime Mudstone: These deposits are represented by mud-supported lithotypes sometimes formed by very thin laminae, generally with shell fragments and characterized by the dominant presence of siliciclastic grains and dolomitization (Figure 6B, 6C).

C3. Lime Mudstone: this microfacies is characterized by yellow to brown, thin-layered to laminae limestones. Clastic quartz grains and well-rounded rock fragments up to 5% is present in this microfacies (Figure 6C).

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Interpretation: This facies was deposited in tidal flat environment, as indicated by evaporate cast and Birdseye fabric as well as stratigraphic relationships with the C4. In accordance to the standard microfacies type described by Flugel (2010), C3 is interpreted to have been deposited in tidal flat.

C4. Bioclast Wackestone: This microfacies is characterized by dark gray, thin-bedded fossiliferous limestone. This microfacies is lime mud-dominated with wackestone fabric. The main components of this facies are bioclast fragment of green algae (10-30%), gastropods and echinoids. clastic angular to subangular, very fine grained quartz are subordinate component (Figure 6D).

C5. Bioclast Intraclast wackstone/packstone: This microfacies is gray to dark gray, medium to thick bedded limestone in the field. This facies is characterized by the presence of intraclast and gastropods, shell fragments and green algae. Peloids are also present. The matrix is fine-grained micrite (Figure 6E).

Interpretation: The limited diversity of fauna, dominance of micrites and the stratigraphic position indicate deposition in a low-energy lagoonal environment (Gholamalian and Kebriaei, 2008).

Lagoon Facies Belt (D)

D1. Bioclast packstone: in the field this facies is in the form of dark gray, thick-bedded limestone. In this microfacies bioclast (mostly echinoids) and peloids are present (Figure 7A). This microfacies has a fine-grained matrix. This facies mostly occurs in the lower parts of the Bahram Formation.

D2. Pelloid Bioclast Wackestone to Packstone: The main allochems of this microfacies is the diverse bioclasts pelloid in mud-supported textures. Rare to common green algae are also present. Subordinate components are echinoids, Brachiopoda, peloids and gastropods (Figure 7B).

D3. Peloid Packstone: Field exposure of facies consists of medium to thick-bedded light gray limestone. This facies is characterized by the presence of pelloid and micritized bioclasts. Gastropods, Umbella algae and echinoids are also present (Figure 7C).

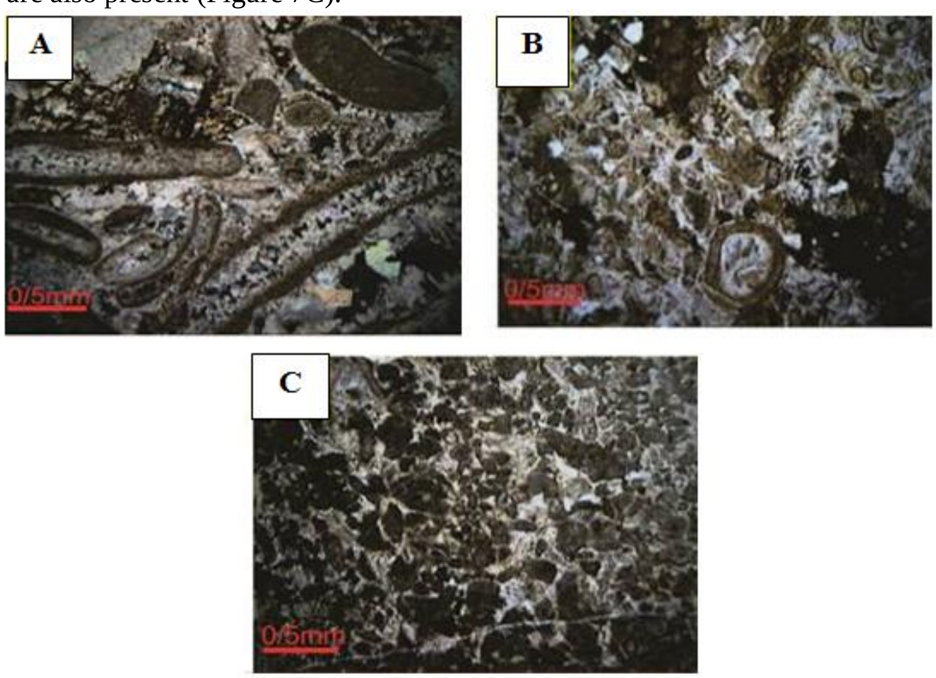

Figure 7: photomicrograph of lagoon microfacies. A: Bioclast packstone, XPL. B: Pelloid bioclast wackestone to packstone, PPL. C: Peloid Packstone.

Interpretation: Lagoonal biota and presence of micrite with packstone textures suggest deposition in the low-energy lagoon environment. The diversity of the fauna shows that the primary environment had good water circulation and normal salinity and oxygen content within the water column and the sediment

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surface. The existence of green algae indicates good aeration and light penetration (Samanckassou *et al.*, 2005).

Patch Reef (E)

E1. Bryozoer Bondstone: In the field, this microfacies is dark cream to brown, thick to medium bedded limestone. This facies is dominated by bryozoa fragments with boundstone textures. Subordinate components are peloids, echinoid debris, brachiopoda debris, green algae, bivalves and intraclasts (Figure 8A).

Interpretation: Due to the dominance of coarse and thickend bryozoa sckelt, with bounstone texture and associated lagoonal microfauna, this facies is deposited as patch reefs in lagoonal environments.

E2. Coral Boundstone: This microfacies is dark cream massive limestone and with no lateral distribution. Large coral fragments and echinoid debris are the main components of this microfacies. Subordinate components include %5 of bryozoa. Intraclast is non-skeletal allochem of this microfacies (Figure 8B).

Interpretation: The faunal components and textural features suggest that this microfacies is formed as patch reefs in lagoonal environments.

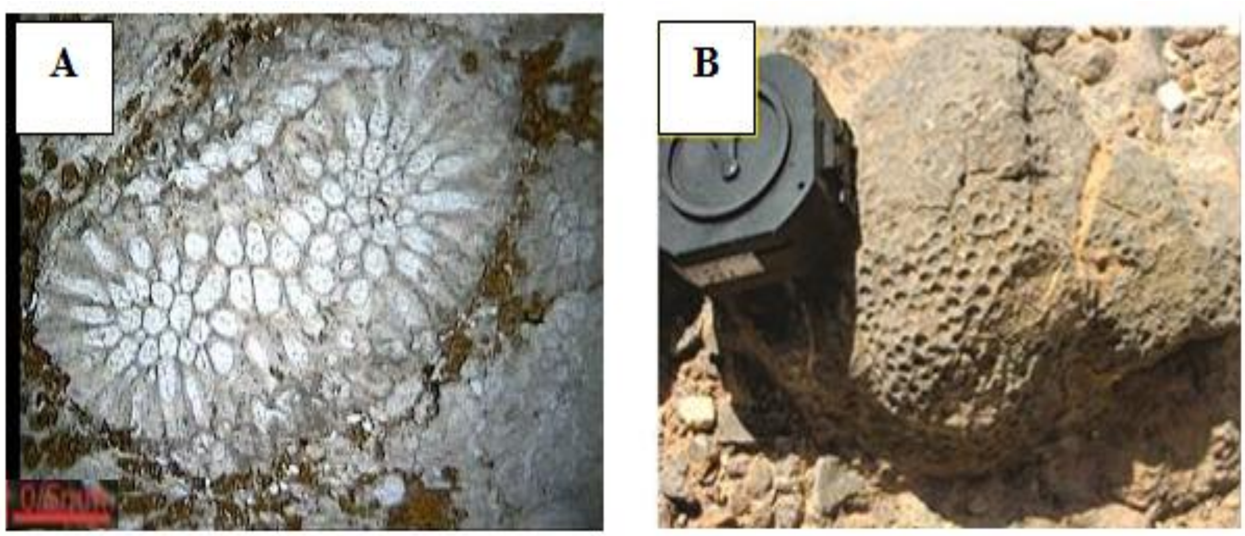

Figure 8: A: Photomicrograph of bryozoa boundstone, PPL. B: filed photograph of coral boundstone

Barrier Belt (F)

F1. Ooid Grainstone: This microfacies is characterized by the presence of about 80% ooids with the size of ~60mm. Ooids occurre in the form of radial, well-sorted concentric and surficial. Subordinate allochems of this microfacies is bioclasts of brachiopods (Figure 9A).

F2. Intraclast Bioclast Grainstone: This facies is formed of different bioclasts including corallinacean and echinoids, Bryozoa and Textullarids. The components are poorly to moderately sorted (Figure 9B).

F3. Ooid bioclast grainstone: The main characteristics of this microfacies are the presence of fine grains of ooid and bioclasts of echinoid, green algae and peloids with grain-supported textures. Minor particles of brachiopods, gastropods and green algae are also present (Figure 9C). Angular, fine grained monocrystalline quartz with the amount of 5% is non-carbonate elements of this microfacies.

Interpretation: The depositional environment is interpreted as a shoal environment. This interpretation is supported by the faunal components, first-stage marine rim cement, grain-dominated texture, high degree of fragmentation of bioclasts (Flugel, 2010) and stratigraphic relationships.

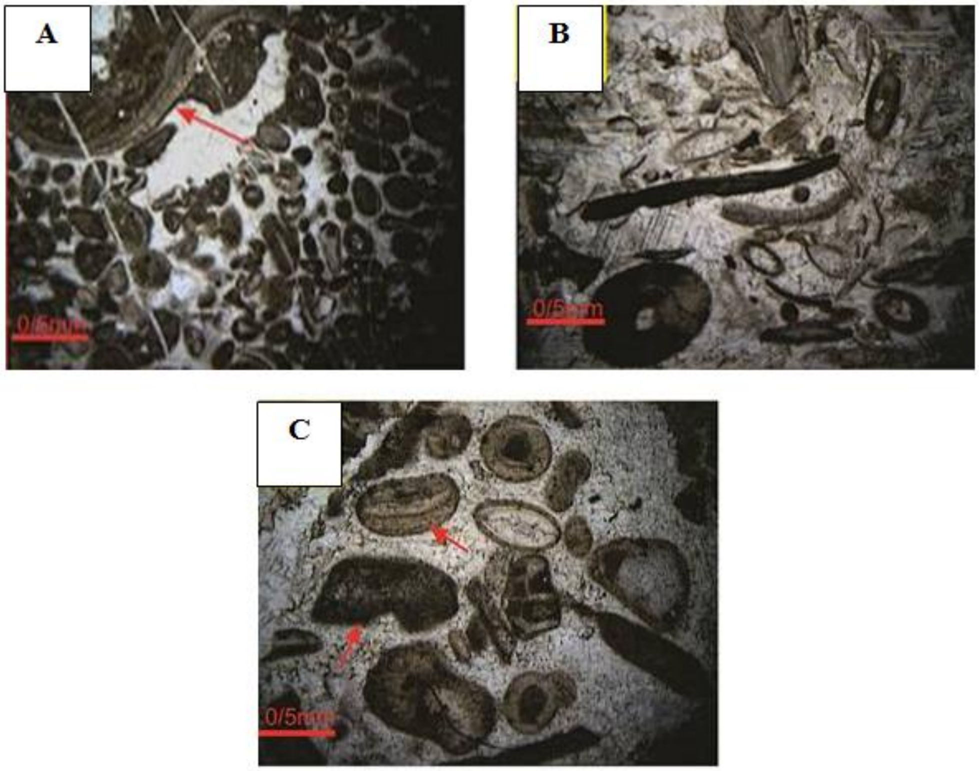

Figure 9: photomicrograph of barrier. A: Ooid grainstone, PPL. B: Intraclast bioclast grainstone, PPL. C: Ooid bioclast grainstone, PPL.

Proximal Open Marine Facies Belt (J)

J1. Intraclast Ooid wackestone/Packstone: This facies is found in the thick to massive beds of the lower part of the Sardar section. It is dominated by concentric, radial and surficial ooid (40%), intraclast (30%) and bioclasts including brachiopods and echinoid debris and peloids. This microfacies has a fine-grained matrix (Figure 10A).

J2. Bioclast Wackestone to Packstone: The components of this microfacies are dominated by bioclast grains such as echinoids, crinoids and brachiopods. Monocrystalline quartz grains with the size of 0.2 mm (3%), subrounded micritic intraclast (5%) are subordinate elements of this microfacies. Thirty percentage of micrite can be observed (Figure 10B). Chert nodules are common in all intervals with this microfacies. This facies is common in the Upper part of the Bahram Formation.

Interpretation: This facies was deposited in a low to medium energy, open marine environment. This interpretation is based on the presence of marine fauna like echinoids, crinoids and brachiopods and stratigraphic relationships. Wanas and Abdel-Maguid (2006) considered similar facies as representative of an open marine environment.

J3. Grainstone to Packstone with Phosphorate: This microfacies in the field consists of 3 medium bedded dark brown to black limestone and present in the upper and lower parts of the Bahram Formation. They are intercalated with thin layered limestone and shale. Skeletal grains were cemented with phosphatic cement. Some of the allochems are replaced with phosphate. Well rounded, monocrystalline to polycrystalline quartz grains with the amount of 10% are present (Figure 10C, 10D).

Interpretation: Stratigraphic relationships (adjacent facies) and phosphatic cement indicates that sedimentation took place in an open marine environment below the fair-weather wave base, with low-energy background conditions.

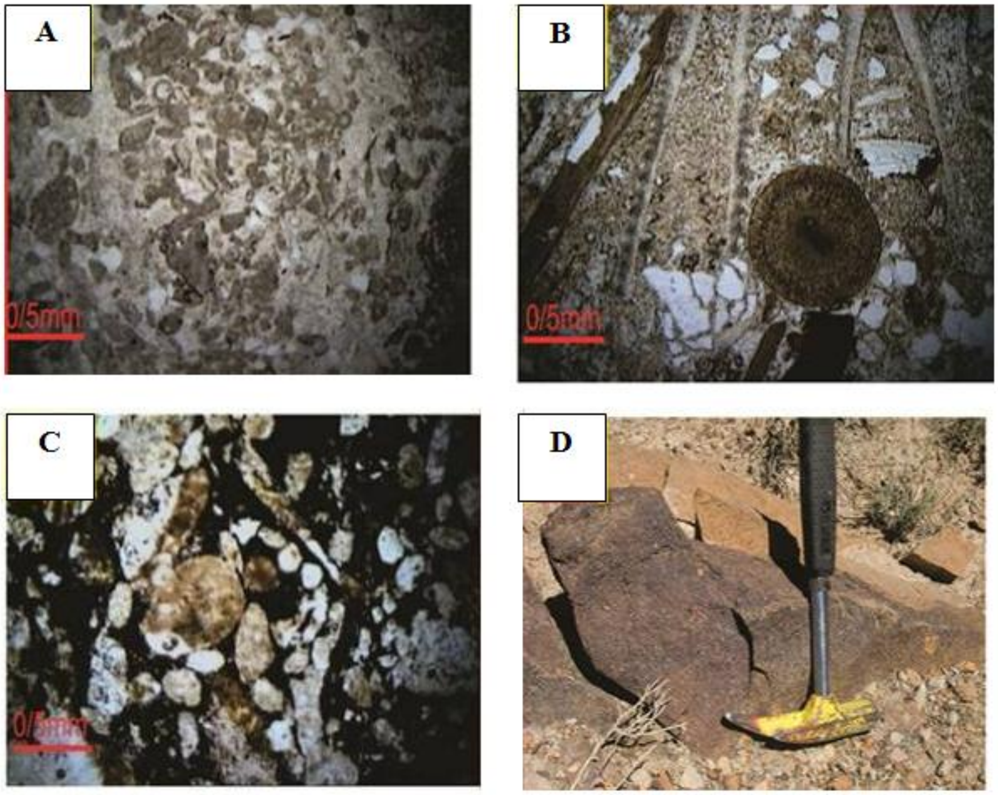

Figure 10: photomicrograph of proximal open marine microfacies. A: Intraclast Ooid Packstone, PPL. B: Bioclast Wackestone/Packstone, PPL. C: Grainstone to packstone with, PPL. D: Fotograph of Phosphoraite Grainstone to Packstone.

Depositional Environment

Based on the field studies and petrographic analysis carried on thin sections, the distribution of vertical facies relationships and comparing the microfacies with those of Wilson (1975) and Flugel (2010), 18 facies have been recognized. This facies have been deposited on five major depositional facies belt in the Late to Middle Devonian succession in the Chatroud area (Figure 11).

These facies belts are shore (A, B), tidal flat (C), lagoon (D), patch reffs (E), shoal (bioclast barrier) (F) and proximal open marine (J) environments.

Shore face (A, B) belt can be divided into 4 subenvironments, A1: shore face, A2: foreshore, A3: offshore and B1: offshore to tidal flat.

Tidal flat is consists of the microfacies C1 to C5. This facies belt starts with dolostone and then intraclasts and then bioclasts are presents. Tidal flat facies are characterized by fenestral fabric, clastic quartz, and thin-bedded pattern. The wavy or flat-laminated sandstone are formed by very sorted and binding fine-grained in the upper intertidal zone (Palma, 2007). Lagoon facies belt is characterized by the presence of peloid, gastropod, green algae and other micritized bioclasts. The presence of micrite indicates the low-energy environment (Microfacies D1 to D3). Patch reefs are present. In this environment patch reefs and the E1 and E2 can be assigned to this environment. Grain-dominated texture, lack of micrite and marine rim cement are the indicators of high energy environment and microfacies F1 to F3 are referred to this facies belt (Penney, 2004). Based on marine microfauna, presence of phosphatic microfacies J1 to J3 were deposited in proximal open marine environment (Husinec and Read, 2007).

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These 6 depositional environments of the Middle to Late Devonian in the Chatroud area are similar to those found in many modern carbonate depositional settings (Bachmann and Hirsch, 2006). Of these, the Persian Gulf is the best modern analogue for inferring ancient water depths because it shares many similarities with the Central Iran Basin during Middle to Late Devonian. Both settings represent peripheral shallow basins with similar basin geometries and comparably shallow depositional (Nader *et al.*, 2006). Therefore, a carbonate ramp platform sedimentary model can be applied to these ancient carbonate deposits (Tucker and Wright, 1990; Tucker, 2001) (Figure 12).

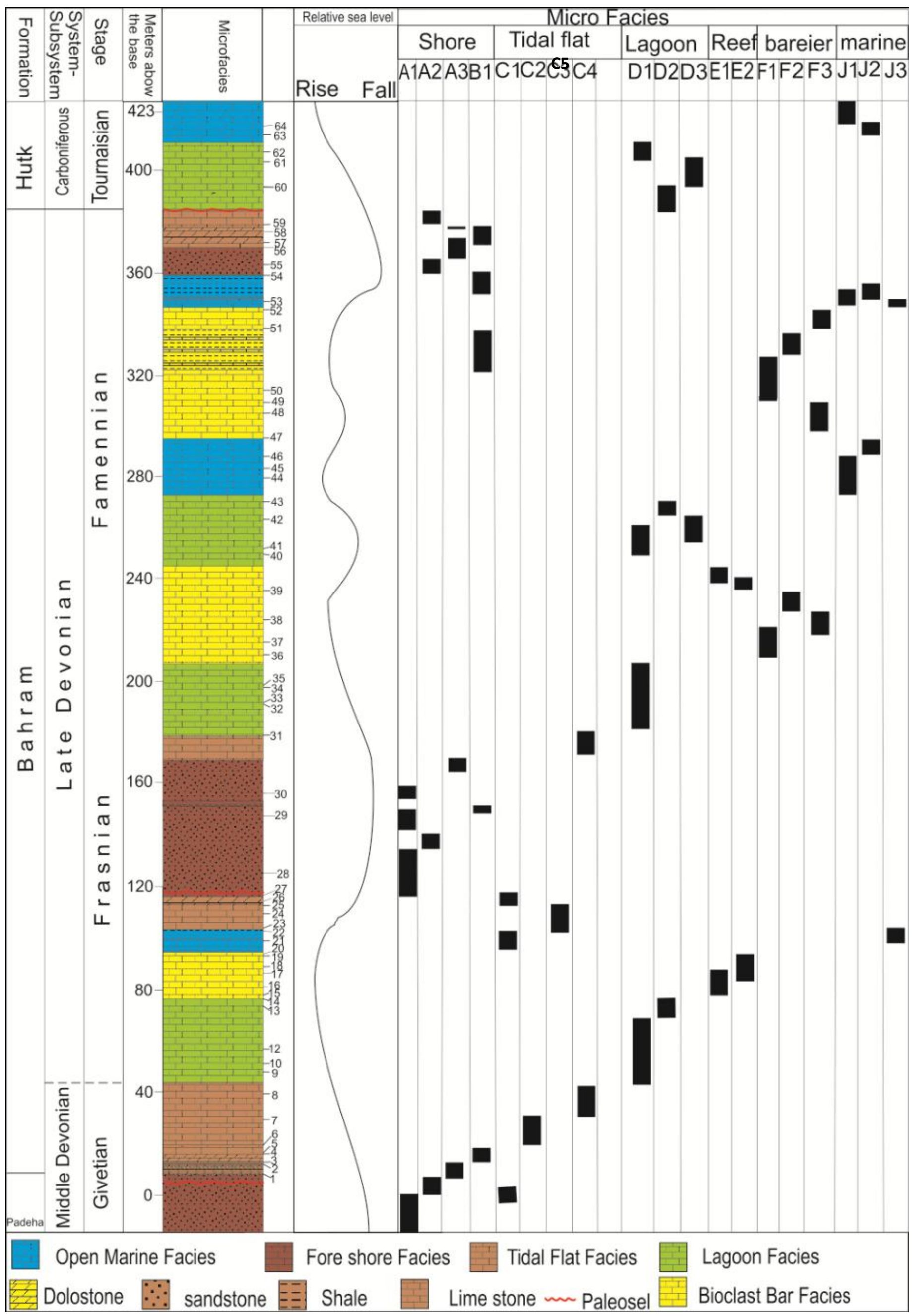

Figure 11: Petrographic and Sedimentological log of the Bahram Formation in the Sardar Section

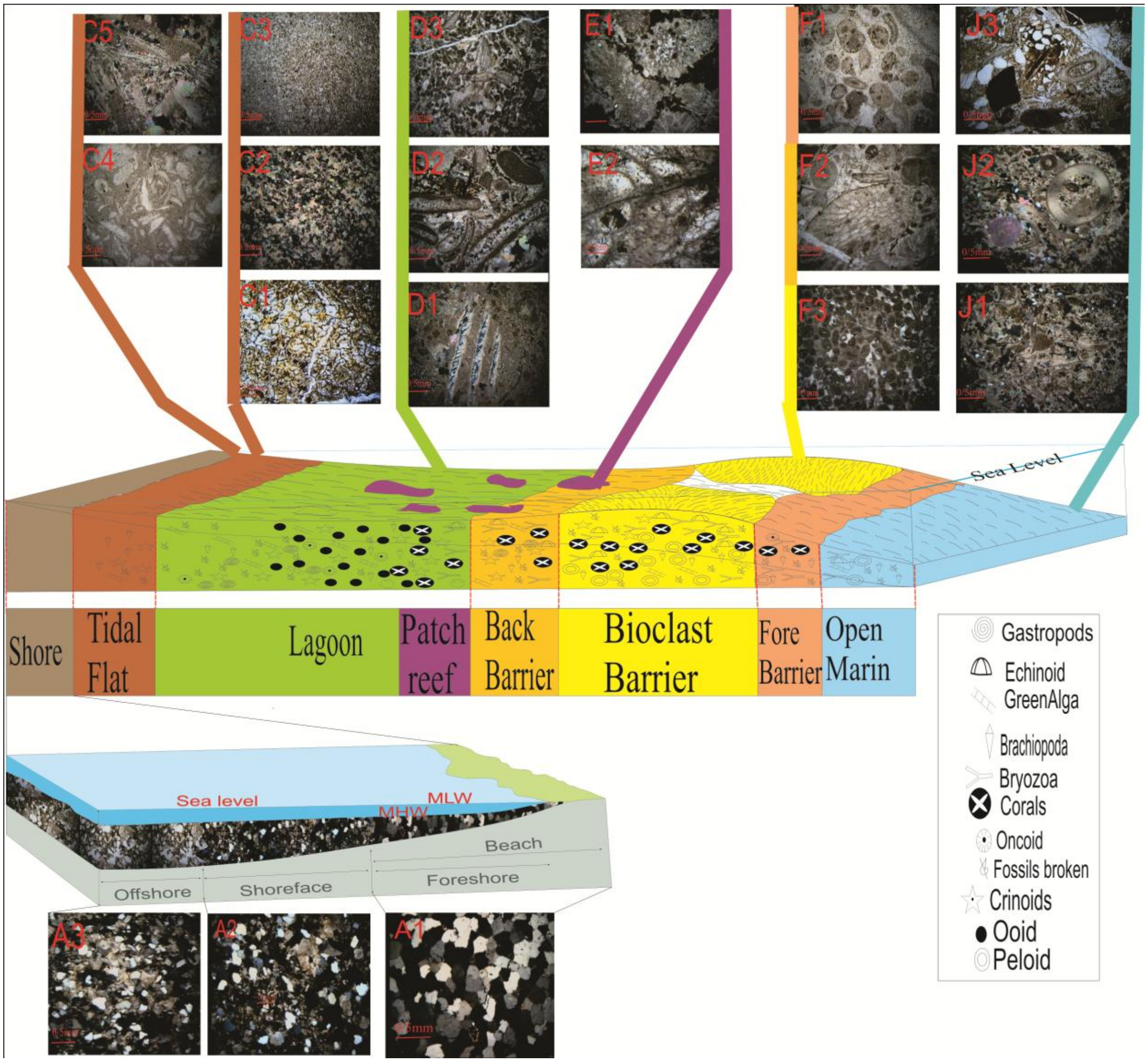

Figure 12: 3D depositional model of the Bahram Formation in the Chatroud area

Conclusion

Based on field study and petrogrphic analysis of thin sections of the Bahram Formation 20 microfacies have been identified. These microfacies are related to five facies associations including shore, tidal flat, lagoon, barrier and proximal open marine. Based on the gradual change of microfacies to each other, the lack of great barrier reefs and lack of calciturbidite it can be concluded that the facies have been deposited on a homoclinal ramp platform with mixed carbonate –siliciclastic deposits.

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