Revista Geoaraguaia
ISSN:2236-9716
Barra do Garças - MT
v.10, n.1, p.7-23. Jun-2020

FACIES, DEPOSITIONAL ENVIRONMENT, DIAGENESIS AND SEQUENCE STRATIGRAPHY OF JAHROM FORMATION IN BINALOUD OILFIELD, PERSIAN GULF

FÁCIES, AMBIENTE DEPOSICIONAL, DIAGÊNESE E ESTRATIGRAFIA DE SEQUÊNCIA DA FORMAÇÃO NO CAMPO PETROLÍFERO DE JAHROM - GOLFO PÉRSICO

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RESUMO

A Formação Jahrom (Paleoceno-Eoceno Médio) é um dos importantes reservatórios da bacia do Zagros e do Golfo Pérsico. Esta formação foi formada no campo de Binaloud, no Golfo Pérsico, com uma espessura total de 660 metros de pedras calcárias e dolomíticas. Neste estudo, foram abordados as microfácies, ambientes deposicionais, processos diagenéticos e estratigrafia sequencial da Formação Jahrom no campo petrolífero de Binaloud. Os depósitos da Formação Jahrom incluem a periodicidade do calcário cristalino e dolomita, com uma borda descontínua abaixo da Formação Asmari e acima da Formação Tarbur. colocado em um ambiente deposicional da rampa de carbonato homoclínico. Segundo estudos petrográficos, os processos diagenéticos mais importantes observados nessa formação são bioturbação, cimentação, dolomitização, dissolução, porosidade e fraturas. Os estudos de estratigrafia de sequências levaram à identificação de uma sequência deposicional do terceiro tipo com um limite seqüencial do primeiro tipo para depósitos da Formação Jahrom.

Palavras-chave: Formação de Jahrom; Campo de Binaloud; Golfo Pérsico; Ambiente deposicional; Estratigrafia de sequência.

ABSTRACT
Jahrom Formation (Middle Paleocene-Eocene) is one of the important reservoirs in the Zagros and Persian Gulf basin. This formation has been formed in the Binaloud field in the Persian Gulf with a total thickness of 660 meters of calcareous and dolomitic stones. In this study, microfacies, depositional environments, diagenetic processes, and sequential stratigraphy of Jahrom Formation in Binaloud oilfield were studied. The deposits of Jahrom Formation include the periodicity of crystalline limestone and dolomite, with a discontinuous border below the Asmari Formation and above the Tarbur Formation.By studying the thin sections obtained from the cutting samples of 11 microfacies were identified in 4 facies assemblages, which were placed in a depositional environment of the homoclinic carbonate ramp. According to petrographic studies, the most important diagenetic processes observed in this formation are bioturbation, cementation, dolomitization, dissolution, porosity and fractures. Sequence stratigraphy studies led to the identification of 1 third-type depositional sequence with a first-type sequential boundary for Jahrom Formation deposits.
Keywords: Formation of Jahrom; Binaloud Field, Persian Gulf; Depositional environment; Sequence stratigraphy.

INTRODUCTION

Cenozoic sediments in the sedimentary basin of the Zagros, Persian Gulf, and Arabic platforms have always been of particular interest due to the huge oil reservoirs (Alavi, 1994; Berberian and King, 1981; Sengor, 1984; Hessami et al., 2001). A large proportion of these hydrocarbon sources are found in Asmari and Jahrom formations in the Zagros and Arabic platforms (Alsharhan & Nairn, 1997). Hence, the deposits of this formation and its equivalents have been studied in different regions. The sample section of Jahrom Formation in Tangab, on the slopes of Mount Jahrom, (200 km southeast of Shiraz, Fars province) has been measured and defined (Motiee, 1993). In the sample section, this formation is characterized by 460 meters of dolomitic limestone and fine grain dolomite with many microfossils (James & Wynd, 1965). So far, researchers have studied this formation in terms of depositional environments and sequence stratigraphy (Seyrafian, 1988; Vaziri-Moghadam et al., 2002; Nadjafi et al., 2004; Taheri et al., 2008; Sharland et al., 2001). In this study, diagenetic processes and sequence stratigraphy were investigated. In this area, Jahrom Formation is about 660 m thick. Binaloud field is located in the southeast of the Persian Gulf and 60 kilometers from the Persian island (Figure 1). This research can be used for stratigraphic adaptation in adjacent oilfields.

Revista Geoaraguaia
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Barra do Garças - MT
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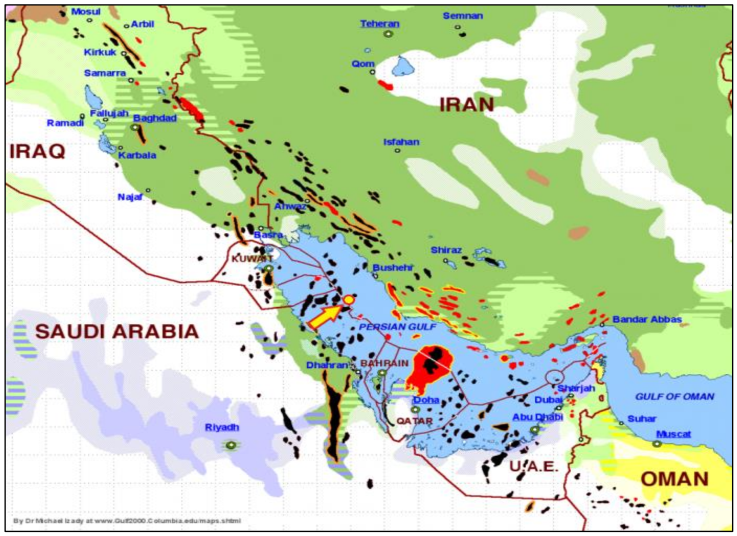

Figure 1: Location of the Binalood oilfield in the Persian Gulf.
Source: NATIONAL IRANIAN OIL COMPANY (2006)

METHODOLOGY

In this study, 440 thin sections obtained from the cutting of wells No. 4 and 5 were used for identifying facies. Well No. 5 has been located southwest of well No. 4. The thickness of Jahrom Formation in well No. 4 is 659 meters and in well No. 5, 666 meters. From the sections studied, 226 sections are related to well No. 4 and 214 are related to well No. 5. The naming of facies was done by Dunham method (1962). Gamma and audio electrical logs were used to reduce the error of cutting samples. Also, the diagenetic processes in the Jahrom Formation were studied. After identifying facies and diagenetic processes, regeneration of long-standing depositional environments was carried out according to Walter's law and by comparing the depositional environments of the present covenant. On the basis of vertical changes of facies and sudden changes in depositional environments, diagenetic processes and sedimentary discontinuities, sediment sequences were identified. Also, sedimentary sequences and facies groups were studied according to Van Wagoner et al. (1988), and then diagenetic complications were detected in microscopic sections.

STRATIGRAPHY

The name of Jahrom Formation is inspired from Jahrom Mountain, south of Jahrom, about 200 km southeast of Shiraz in Fars province. The sample cut has been introduced by James and Wynd (1965). The sampl cut of the Jahrom Dolomite Formation in Tangab, has been measured in the northern edge of Mount Jahrom, south of Jahrom city, in Fars province. This formation is also called Eocene limestone and Gishoon limestone (Motiei, 1993). Jahrom Formation is located in the Binaloud Field in the Persian Gulf with a total thickness of 660 meters of calcareous and dolomitic stones. This formation in the well No. 4 of Binaloud oilfield is often dolomitic in which thin layers of anhydrite with some clay are observed (National Iranian Oil Company, 2006). The Jahrom Formation in well No. 5 has a significant similarity to the deposits of Jahrom Formation in well No. 4 in terms of stratigraphy, and its major lithology is dolomite and calcareous. However, the amount of anidrite layers is thicker than that of well No. 4. The clay content is also found in Jahrom Formation No. 5 (National Iranian Oil Company, 2007). Jahrom Formation in both wells studied with discontinuity is located above the Tarbur Formation and below the Asmari Formation.

Khaneh-Zu Formation is somewhat heterogeneous at different scales due to extensive facies changes, effect of diagenetic processes horizontally and vertically and tabular communication in some areas with Chaman-Bid Formation. Diagenesis is the main controlling factor in many of hydrocarbon reservoirs, especially in Middle East. Diagenetic history of sediments is controlled by sea water level fluctuations (Sarg, 1988; Emery and Meyers, 1996; Sanjary and Hadavi, 2019). This formation is composed of porous zones and permeability as well as intra-reservoir non-porous horizons. Such heterogeneities and extensive changes made it essential to discuss factors affecting and controlling microfacies and diagenesis.

This study was conducted to introduce microfacies, depositional environment, and effect of diagenetic processes on Khaneh-Zu Formation in Kopet Dagh Basin.

GEOLOGY AND STRATIGRAPHY

The studied sections are located in Kopet Dagh at north east of Iran (Figure 1). Kopet Dagh is a part of Alpine Himalayan System that was formed after the closure of the Paleo-Tethys. This area is the second hydrocarbon basin in Iran (Kavoosi et al., 2009; Poursoltani, and Hrati Sabzvar, 2019). In Kopet Dagh area, upper-middle Jurassic shale and Chaman-Bid Formation are the source rock in this sedimentary basin (Afshar-Harb, 1979). Carbonate rocks of Mozduran Formation is the main gas reservoir in this basin (Afshar-Harb, 1979).

MICROFACIES

By studying thin sedimentary sections, sedimentary texture and the components of thin sections of Jahrom Formation in Binaloud field, 11 microfacies were found placed in 4 facie assemblages of tidal environment, lagoon, barrier and open sea stacks. These microfacies are from the shallow environment to the deep environment, respectively:

Sabkha Facies and Tidal Zones

- MF1-Mudstone with anhydrite: This facie contains anhydrite, which shows very little reading in gamma logs. In this facies, anhydrite crystals are visible as compact and crystalline texture. The distribution of anhydrite in the form of nodules and veins in the mud of limestone and dolomite rocks is one of the most prominent features of this facie (Figure 2-a).
- MF2-Dolomudstone with evaporite casts: This microfacies has evaporite casts (gypsum or anhydrite), with glial crackles in the background and dolomite microcrystalline texture. Since most cavities are lens-shaped, they can be considered as evaporite casts. Some evaporite casts and cavities of mud cracks have been filled with calcite sparite. There is practically no fossil or allochoms in this microfacies (Figure 2-b).
- MF3-Dolomitized Peloid Grainstone: The main non-skeletal grain of this microfacies is Peloid with the frequency of about 60%. One of the skeletal components of this microfacies can be the presence of less than 5% of bivalve mollusks. Sediments are connected to each other with sparite cement. In this facies, chistone cavities have been identified. The sedimentation environment of this microfacies is above the effect level of the normal-wave and environment with high energy (Figure 2-c).
- MF4-Peloid Grainstone: This microfacies has about 70% peloid, with a mean diameter of about 0.1 mm. The ecinoderm fragments with bivalvia, gastropods of about 5%, and very small amounts of special foraminifera such as millyoid, and some intracalast are other allochoms of this microfacies (Figure 2-d).

Interpretation of the facies of Sabkha and the tidal zone: The presence of mud cracks, dolomudstone with evaporite casts and anhydrite indicate sedimentation in the tidal zone under dry and warm weather conditions in the southern part of the Persian Gulf (Lasemi, 1995). Peloid Grainstones with low fossil concentrations, based on the sequence of lower and upper facies, can be attributed to tidal channels. The presence of peloids in a Grainstone texture (MF3 and MF4) suggests that the depositional environment of this facies is above the surface of the normal-wave and high-energy environmental effects. MF3 and MF4 facies are closely related to stratigraphy and have support grain texture.

Facies of Lagoon

- MF5-Bioclast Wackestone: This facies contain 10 to 15 percent of the bioclast, which consists mainly of miliolida and a small amount of brachiopod and acinoderm particles. In addition, about 10% of the peloid is observed, which is in the dolomite texture. Miliolida in this microfacies represent the lagoon environment (Figure 2-e).
- MF6-Mudstone: This micrfacies consists mainly of calcareous mud with less than 5% skeletal fragments, such as gastropod (Figure 2-f).
- MF7-Bioclast peloid Wackestone: Milliolida and sometimes other benthic foraminifera with them, such as neo-aleuolines, are the main components of this facies. The sub-components of this facies include peloid 10-15%, acinoderm 3 to 4%, red algae 1 to 2% (Figure 2-g).
- MF8-Bioclast peloid Packstone: The main allochoms of this microfacies is 55% of the peloid dispersed in the calcareous mud context. Skeletal fragments include 5% gastropoda, 5% benthic foraminifera and a small content of bivalvia oyster (Figure 2-h).
- MF9-Bioclast Peloid Packstone to Grainstone: The most important components of this microfacies is peloids and benthic foraminifera, where peloids are often rounded and includes about 50% of the microfacies. Foraminifera has a small

variety and the frequency of about 15 percent. Some of the foraminifera observed in this microfacies have been micrited (Figure 2-I).

Interpretation of the lagoon facies: According to the sequence of facies, which are located between the facies of the dam and the tidal zone and on the other hand, the presence of fossil fonaites such as mullivide and gastropod, where the index of closed environments have higher salinity, all of them signify the sedimentation of these facies in the semi-enclosed lagoons behind the dam. The presence of red and crescent algae with skeletal fragrances indicates better marine and biological conditions which can be attributed to the relative increase in seawater levels. Microfacies MF9 have a close stratigraphic relationship with MF7 and MF8 facies. However, the sparite field in this facies is increasing and indicates the proximity of the environment to the dam.

Facies of Dam Stack

- MF10-Bioclast peloid Grainstone: This microfacies is predominantly grain supportive and has about 65% peloid. The echinoderm fragments are 10%, with a small amount of bivalves and gastropods of other allochoms of this facies (Figure 2-J).

Interpretation of Dam Stack Facies: The absence of calcareous mud among skeletal and non-skeletal grains indicates high energy and its high continuity in depositional environments. The presence of cement indicates a large pumping of water into the carbonate sequence.

Open-sea facies assemblages

- MF11-Dolomitized Bioclast Wackestone to Mudstone: There are about 5 to 15 percent of small skeletal fragments including planktonic foraminifera, echinoderm, and plagic bivalve. The presence of Pyrite represents the deep burial conditions of this facies. This facies formed below the normal surface of the waves where the energy was the lowest (Figure 2-k).

Interpretation of Open Sea Facies: The presence of planktonic foraminifera and thin shell bivalves in stratigraphic sequences and read more of gamma logs all refer to sedimentation in the facies belt of the open sea and below the wave base. Also, thin shells of bivalves indicate the high depth of depositional environments of this facies.

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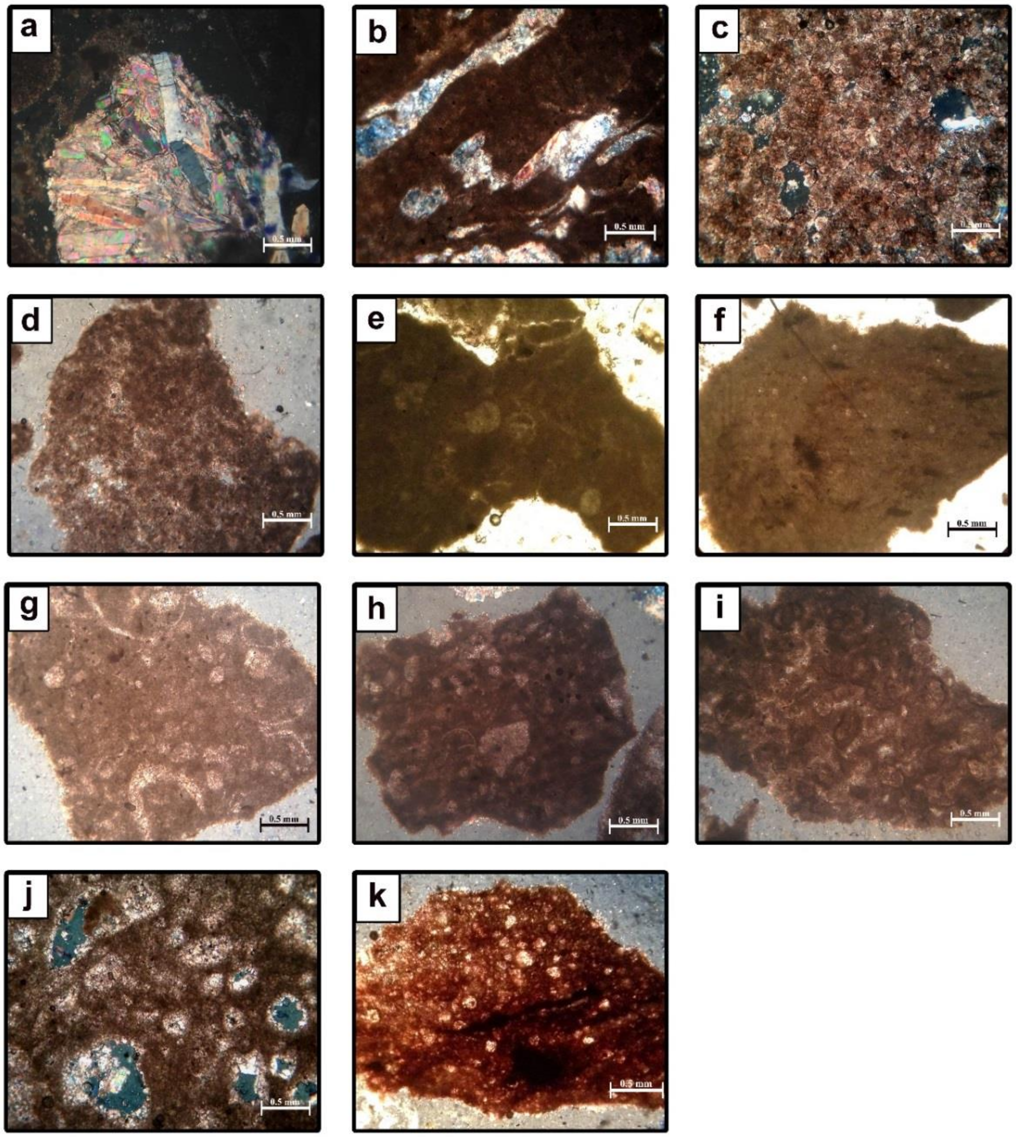

Figure 2: The microfacies of Jahrom Formation in Binaloud Field: a) Mudstone containing anhydrite, polarized light; b) Dolomudstone with evaporite casts, polarized light; c) Dolomitized peloid grainstone; polarized light; d) Peloid Grainstone, polarized light; e) Bioclast wackestone; Normal Light; f) Mudstone; Normal Light; g) Bioclast peloid wackestone, Normal Light; h) Bioclast peloid wackestone, normal light; i) Bioclast peloid packstone to grainstone, normal light; j) Bioclast peloid grainstone, polarized light; k) Dolomitized Bioclast Wackestone to Mudstone, polarized light.
Source: Writers.

SEDIMENTATION ENVIRONMENT

Based on the type of facies, their vertical and lateral changes, the type of components and their comparison with the old and present environments, the sedimentary model of Jahrom Formation has been rebuilt in the studied oilfield (Fig. 3). Regarding the identified facies, the trend of their gradual changes from deep to shallow sections, the great presence of lagoon and bioclast facies, the absence of deposits from turbidatia flows, slipping and sloping sediments, the lack of reefs, the absence of oncoids, pezoids and cumulative grains that are specific to carbonate tufts (Flugel, 2010) and comparing them with the standard facies (Flugel 2010) and comparison with the models presented by other researchers (Wilson, 1972; Carozzi, 1989; Einsele, 2000; Tucker, 2001) indicates the sedimentation of the Jahrom Formation in the tidal, lagoon, dam stack and shallow open sea facies belts with sedimentary on a low-slope ramp carbonate platform (Burchett and Write, 1992) (Figure 3).

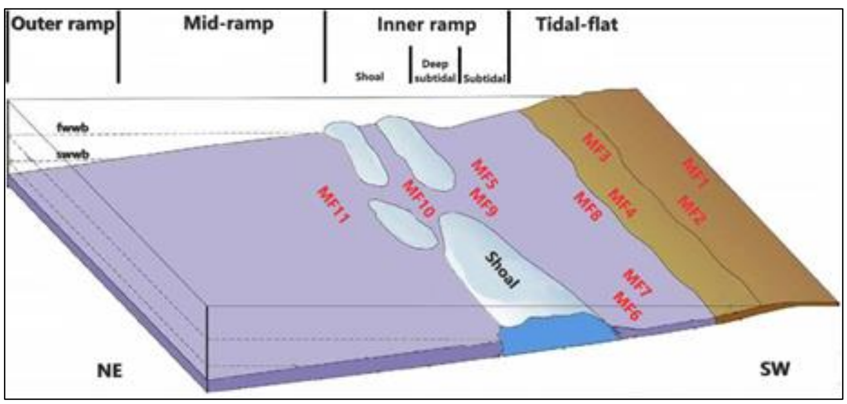

Figure 3: Sediment model of deposits of Jahrom Formation in Binaloud field based on study of sedimentary thin sections of wells Nos. A and B.
Source: Writers.

By studying the frequency of microfacies in wells No. 4 and No. 5, their abundance can be found in wells. Accordingly (Figure 4) in each of wells No. 4 and No. 5, the highest frequency of facies related to facies number 9 Bioclast peloid packstone to grainstone) is related to the lagoon environment and, the lowest frequency of identified facies is related to facies number 11 (dolomitized bioclast wackestone to mudstone). The results of the analysis of the above diagrams

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ISSN:2236-9716
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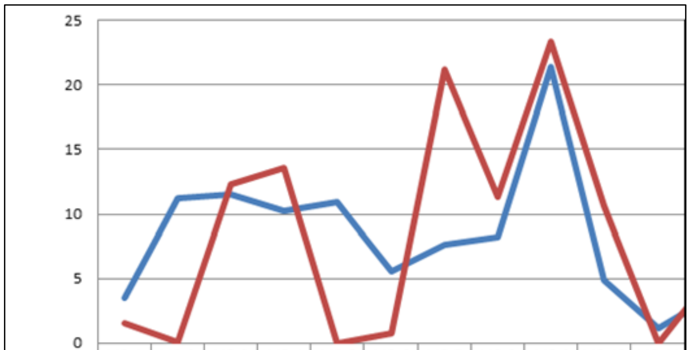
show that deposits of Jahrom Formation in the wells studied from Binaloud oilfield have deposited more in the depositional environment of the lagoon facies.



	MF-1	MF-2	MF-3	MF-4	MF-5	MF-6	MF-7	MF-8	MF-9	MF-10	MF-11
BB-4	3.5	11.2	11.5	10.3	10.9	5.6	7.6	8.2	21.4	4.9	1.2
BB-5	1.5	0.1	12.3	13.6	0	0.8	21.2	11.3	23.4	10.6	0

Figure 4: Frequency diagrams of identified facies in Jahrom Formation in two wells of No. 4 (blue) and No. 5 (red) of Binaloud field.
Source: Writers.

DIAGENESIS

Calcareous sediments are immediately affected by various diagenic processes immediately after sedimentation in different environments (Tucker, 1991; Moore, 2001) and, the diagenesis history of calcareous deposits is related to sea-level fluctuations (Sarg, 1988; Emery & Meyers, 1996). The major diagenetic processes of Jahrom Formation at Binaloud Field are as follows:

Bioturbation: This process is performed immediately after sedimentation and on the sediments, and it is a feature of the lagoon facies belt, which is shaped more often in marine phryatic environment (Tucker and Wright, 1990). In Binaloud Oilfield, there is a great deal of bioturbation in the Jahrom Formation. Which is observed in the facies of the internal ramp, in the form of the dismemberment of the classes and the effects of excavation of organisms on sediments and biogas. The intense biological activity causes changes in the texture and quality of the reservoir and, as a result, porosity reduction. The abundance of bioturbation is due to low sediment production. So that creatures have had the opportunity to disturb the order of sediment for feeding or life (Figure 5-a).

- Anhydrite cement: This cement is seen as a massive large crystal. Based on petrographic evidence and previous work, pervasive cement is a cementitious deposit environment in which anhydrite crystals have been able to grow greatly under physicochemical conditions. This process was further identified in the upper sections of Jahrom Formation. This cement has grown in the secondary pores, including intra-section, inter-crystalline, cavity and cast, and has reduced the reservoir feature (Figure 5-b).
- Dolomitization: Dolomite formed crystals have been formed in Jahrom Formation sediments, which are the characteristics of the burial diagenesis. Due to the low permeability of the facies of Jahrom Formation, the probability of providing Mg^{+2} ion for dolomitization out of the diagenetic system is very low. Calcareous mud, which is one of the main constituents of the facies of the Jahrom Formation, can be one of the most important sources of magnesium ion supply for dolomitization (Hood et al., 2004; Torok, 2000). Most likely, the microcrystalline dolomites found in some of the internal ramp facies of Jahrom Formation, which are accompanied by evaporite casts, are formed in the sabotage environments (Figure 5-c).
- Dissolution: Thin section studies of Jahrom Formation deposits in the studied field indicate that these deposits have been dissolved in some parts of the water out of the water and due to the penetration of atmospheric waters by some of the bioclasts and is seen in the form of porosity in this formation. There are many reasons for the formation of secondary porosity in the depths of the earth including the mixture or cooling in salty waters in deep conditions (Esteban & Taberner, 2003; Vandeginste et al., 2006), carbonic acid produced from Co_2 due to oil bacterial degradation (Benchilla et al., 2002; Story et al. 2000), the transfer of non-organic carbon dioxide by faults and fractures from outside into reservoirs of various origins (Beavington-Penney et al., 2006). This type of process has occurred extensively in the MF2 facies and has led to the dissolution of anhydrite crystals.

- Intra-grain porosity: This porosity contains empty spaces within skeletal fragments and is directly related to the frequency of fossil fragments, their size and type in the rock. The permeability is usually low in this type of porosity. The bulk of the intra-grain porosity is seen in milliolid oysters. Therefore, this porosity is seen in the microfacies formed in the lagoon and the dam stacks (Figure 5-d).
- Cast porosity: This type of porosity in the studied formation is mostly due to the dissolution of skeletal grains such as milliolid and bivalve oysters. The placement of evaporite casts in MF1 and MF2 facies reflects this type of diagenetic process (Figure 5-e).
- Cavity porosity: This type of porosity results from the dissolution of a part of the rock. In the Jahrom Formation, it seems that the cavities have become larger by dissolution of the cast pores. These pores are several millimeters in diameter. Cavity porosity is commonly found in highly dolomitized carbonates, which is associated with delay diagenesis. This type of porosity has the highest contribution in carbonate reservoir portions with an average about 10 to 12% (Figure 5-f).

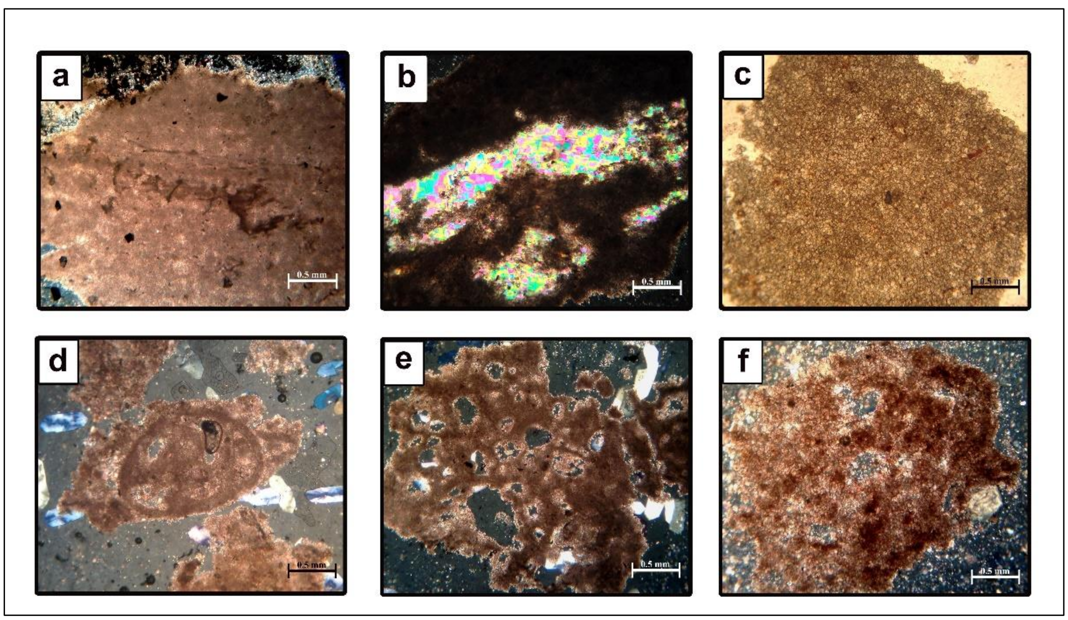


Figure 5: Diagenetic processes in Jahrom Formation: a) Bioturbation, depth of 975, polarized light; b) anhydrite cement, depth of 1105, polarized light; c) dolomitization, depth of 1125, normal light; d) Intra-grain dissolution-porosity, depth of 1201, polarized light; e) cast dissolution-porosity, depth of 1210, polarizing light; f) cavity dissolution-porosity, depth of 984, polarized light.

Source: Writers.

SEQUENCE STRATIGRAPHY

Facies and diagenesis studies in the form of sequentce stratigraphy can be very helpful in understanding the hydrocarbon systems in carbonate reservoir rock and how it changes (Murris, 1980; Moore, 2001; Beiranvand *et al.*, 2007). In general, the lateral distribution of sedimentary facies is related to the depositional environment, while the vertical deposition of facies is determined by sea surface fluctuations and, it reflects the stratigraphic framework (Schlager, 2005; Roger, 2006).

Based on the presented models (Van wagoner et al, 1988), in the deposits of Jahrom Formation, a third-type sequence was identified. This sequence consists of a progressive facies group (TST) which indicates a rapid rise in the relative level of sea water, and its evidence includes the formation of a deep facies assemblage on shallow facies. The facies of the Jahrom Formation base began with a periodicity from the relevant facies of the lagoon and reaches the facies assemblages of above water level after reaching the maximum flooding surface (mfs) in this sequence, and finally ends with the Asmari Formation basal facies. The progressive facies group (TST) in this sequence consists of Mudstone (MF6), bioclast wackestone (MF5) and Bioclast Peloid Packstone-Grainstone (MF9) facies, respectively, of the lagoon environment and, at maximum flooding surface (mfs) reaches to the domilitized bioclast wackestone to mudstone microfacies (MF11) as the deepest microdacies of the Jahrom Formation. Small fractures and porosity resulting from dolomitization and dissolution in the facies related to limited sea have increased due to mud abundance and in this section, we see more porosities in the deposits of Jahrom Formation which can help to increase the reservoir quality. The maximum flooding surface (mfs) is determined by the maximum deepening of facies. The high facies level (HST) group is of the largely low-depth open-sea packstone facies related to the limited sea facies. The upper boundary of this sequence leads to a first-type sequence boundary (SB1). The red sediments containing iron oxide and also the observation of the destructive layer containing unpolluted fossils on this boundary indicate that the end sediments of the Jahrom Formation have been exhausted and eroded. Therefore, the upper boundary of this sequence, located between the Jahrom and Asmari Formations, was considered as the first-type sequence boundary. On the other

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ISSN:2236-9716
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hand, the deeper facies placement of the Jahrom Formation base is observed on shallow facies of the Tarbur Formation, as well as evidence such as the old soils, mud cracks and the karstic surfaces prepared in the cores of the wells (National Iranian Oil 2006- 2007) shows that the basal sequence boundary of the Jahrom Formation is SB1.

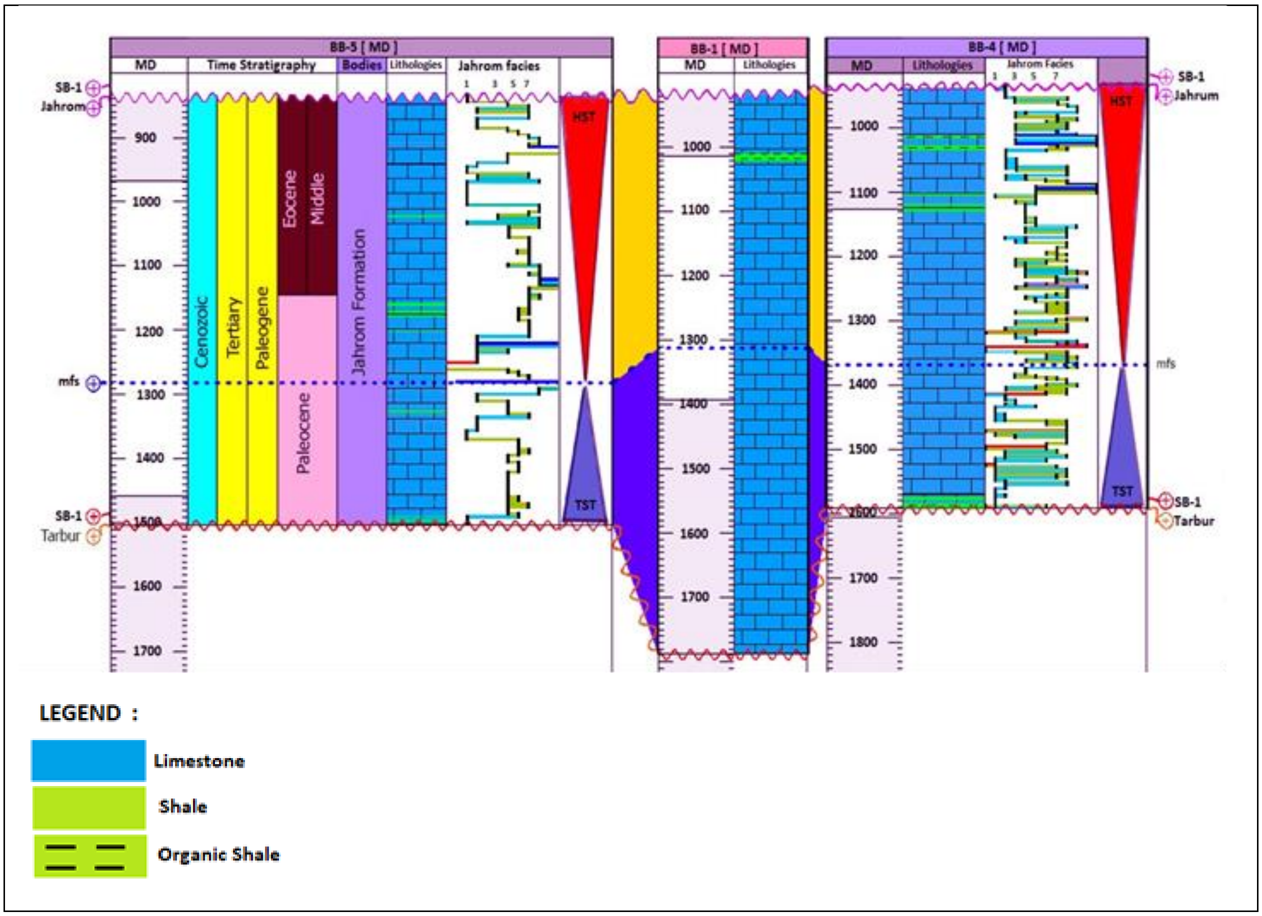

Figure 6: Adaptation of sequence stratigraphy in the studied wells.
Source: Writers.

CONCLUSION

The study of thin sections of Jahrom Formation led to the identification of 11 microfacies in Binaloud oilfield, which were laid out in four facies assemblages of tidal, lagoon, dam stack and open sea envirnment. Based on the type of microfaciess and their vertical variations in the studied sequence, it can be suggested that the Jahrom Formation in the Binaloud field is formed in a depositional carbonate ramp environment. The results of the analysis showed that Jahrom Formation deposits in the studied field have expanded more in the shallow areas of the carbonate platform (lagoon). With the help of microscopic studies on thin sections and the study of facies, a third-type sedimentary sequence was identified in Jahrom Formation, which ends on the first-type sequence boundary above and at the base. According to the studies, the most important diagenetic processes that affect the deposits of Jahrom Formation in the study area are bioturbation, cementation, dissolution and dolomitization.

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