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Reservoir Quality Controlling Factor of the Asmari Reservoir in an Oil Field in Dezful Embayment, SW Iran

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Abstract

The Asmari Formation Oligo-Miocene in age is one of the most important reservoir rocks in SW Iran and Zagros basin and composed of carbonate rocks and locally sandstones and evaporates. In this research, reservoir quality controlling factors have been investigated in a well in one of the oil fields in Dezful Embayment, SW Iran. Based on this research, depositional environment, diagenesis and fracturing have been affected on reservoir quality. 3 distinct depositional settings can be recognized in the studied interval including tidal flat, lagoon, and shoal. Among these depositional setting, shoal environment with ooid grainstone microfacies along with interparticle porosity shows good reservoir characteristics. Diagenetic processes also play an important role on reservoir quality; dolomitization and dissolution have positive effects on porosity and enhances reservoir quality, while cementation, anhydritization and compaction have negative effect on it. Fracturing is another important factor affected on the carbonate reservoirs especially in the Asmari Formation.

Keywords

Asmari Formation, Dezful Embayment, Reservoir Quality, Diagenesis, Depositional Environment

1. Introduction

Iran has major oil and gas resources concentrated in the Zagros folded belt [1]. Structural and stratigraphic features of the Zagros Mountain foothills have been well documented over the past 100 years of oil exploration in Iran [2]. Since the

1908 discovery of oil in the Zagros Mountains foothills of southwest Iran, the main production has been from limestone of the Asmari Formation, a sequence 1050 to 1600 feet (320 - 488 m) thick and Oligo-Miocene in age. In recent decades, oil and gas have also been produced from Mesozoic and Paleozoic reservoir, but the Asmari Formation still remains the most important single production reservoir [3]. Although in Asmari Formation the mechanism of production is related mainly to fracturing and variations in productivity across oil fields within which lithologies are relatively constant have been interpreted to be due to variations in fracture density or spacing, the diagenetic events play an important role in production [4]. Diagenetic factors influence the porosity and permeability, which encompasses all natural changes in sediments occurring from the moment of deposition, continuing through compaction, lithification and beyond-stopping short of the onset of metamorphism [5].

The Asmari Formation disconformably overlies Pabdeh Formation on the southwest side of the Zagros Thrust. It also covered the Jahrum and Shahbazan Formations to the northeastern part in the Fars region, respectively. The upper contact with the Gachsaran Formation is transitional to conformable [6]. The thickness of this formation in type section is 314 m and consists of cream to brown limestone [7]. The Asmari Formation generally consists of limestone, but locally sandstone and evaporites. In Khuzestan province, Ahwaz sandstone member and in Lurestan evaporite Kalhur member have been identified. This formation is investigated by many geologists [8]-[36]. The main objectives of this investigation are determination of microfacies, reconstruction of depositional environments and identification of diagenetic processes and their affect on reservoir characterization on the Asmari Formation in the Qaleh Nar field.

2. Eological Setting

The Zagros Basin is the second largest basin in the Middle East with an area of about 553,000 km^2. It extends from Turkey, northeastern Syria and northeastern Iraq through northwestern Iran and continues into southeastern Iran. This foreland basin developed with the disappearance of Neotethys as suturing began in the northwest and migrated southeast during the Middle to Late Eocene. The suturing was accompanied by crustal thickening and movement along the originally passive margin of the Arabian plate and is related to the spreading movements in the Red Sea-Gulf of Aden. The Zagros Basin is divided into three zones, The Zagros fold-thrust zone, the imbricated zone, and the Urumieh-Dokhtar magmatic zone [37]. The study area is in the Zagros fold-thrust zone (**Figure 1**).

The oil field under study in Dezful Embayment is located 40 km north of Andimeshk city (**Figure 1**). This field was discovered in 1975 by digging well No. 1 by Esco Company and until 1991, a total of three wells were drilled in this field. This field is 60 km long and 4 to 6 km wide in the form of a small anticline on the southern slope of the Balaroud anticline and is on the northernmost border of Dezful embayment. The main reservoirs of this field are Asmari Formation

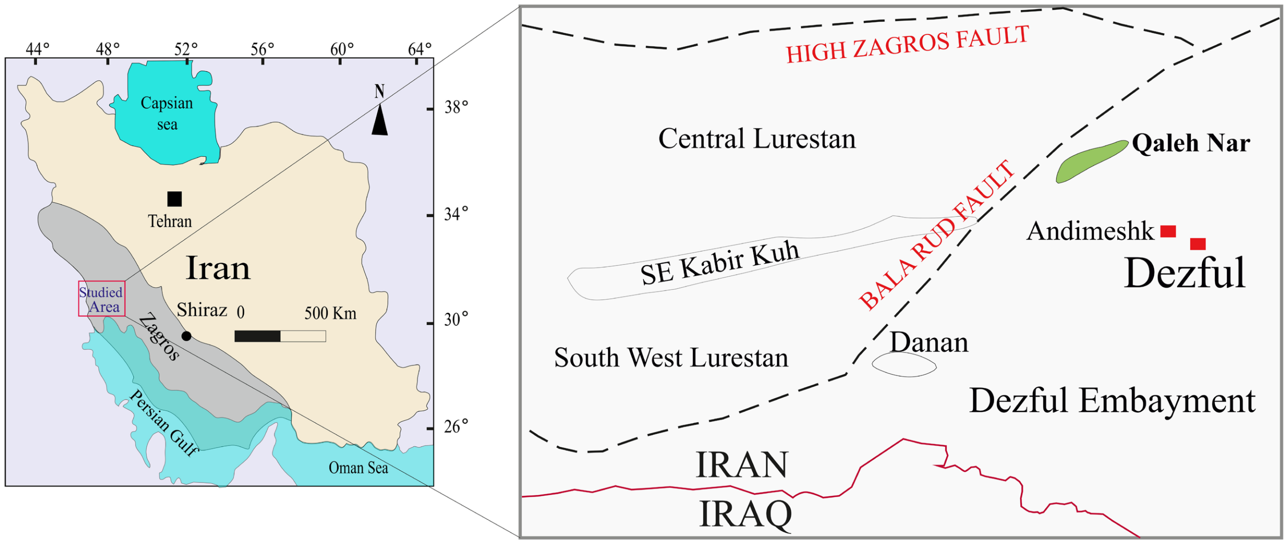


Figure 1. Location map of the Qaleh Nar filed.

and Bangestan Group. Asmari Formation contains oil with API 30 and sulfur 0.8% and Bangestan Group also contains gas [7].

3. Material and Method

For microscopic study, 120 samples have been selected for thin section preparation of the Asmari Formation in the studied well in Qaleh Nar field.

Samples were stained with Alizarin Red-S [38] for determining calcite from dolomite. Thin sections were studied by polarized microscope and different parameters including lithology, texture, sedimentary facies, sedimentary environment, different diagenetic events and types of porosity have been studied. Dunham classification [39] was used for carbonate rocks classification. Flugel [40] comparative diagrams were used to calculate the percentage of rock components [40]. Buxton and Pedly classification [41] for carbonate ramps was used to classify facies. The facies changes of the Asmari Formation have been compared with the studies performed on present and paleo depositional environments (e.g. [42] [43]) and lateral changes were identified according to Walter's law (1973).

4. Stratigraphy

The Asmari Formation (Oligocene to Early Miocene) is present throughout the Zagros Basin, but it is best developed in the Dezful Embayment (**Figure 1**). Lithologically, the Asmari Formation is composed of limestones, dolomitic limestones, argillaceous limestones and shale [7] (**Figure 2**). This formation consists of cream to brown feature-forming limestones with abundant joints. In the northwestern part of the Zagros Basin, the evaporate Kalhur Member interfingers with limestones of the middle Asmari Formation, whereas in the southeast a sandy facies, the Ahwaz Member replaces the limestones. The lower boundary of Asmari Formation with the Pabdeh Formation and the upper boundary with the

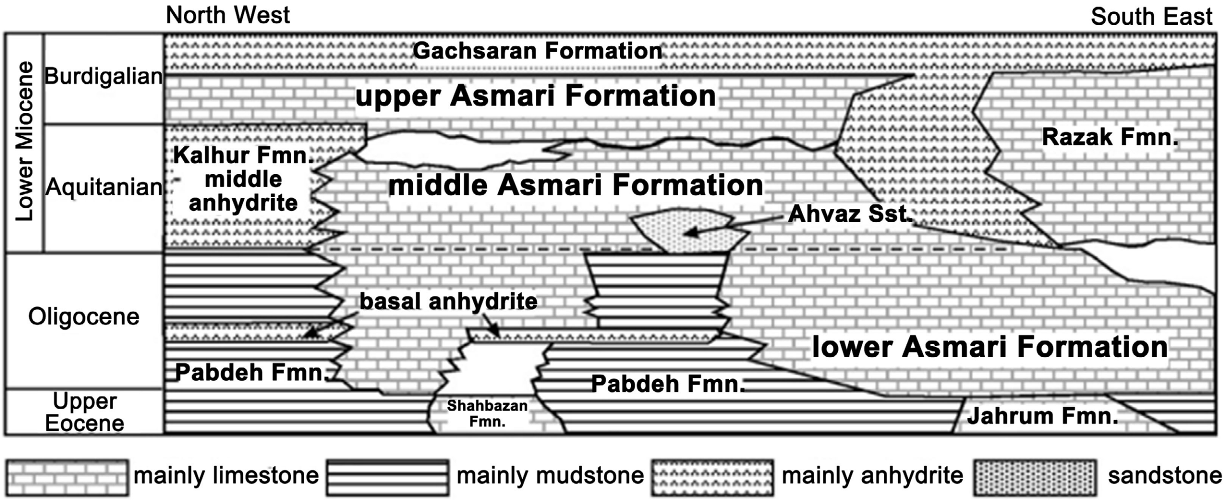


Figure 2. Correlation chart of the tertiary of southwest Iran (adopted from Ala, 1982).

Gachsaran Formation is conformable. Based on the lithological characteristics of the Asmari Formation in the study area, this formation is about 400 m thick and was divided into three distinct parts including lower, middle and upper parts.

5. Facies Analysis

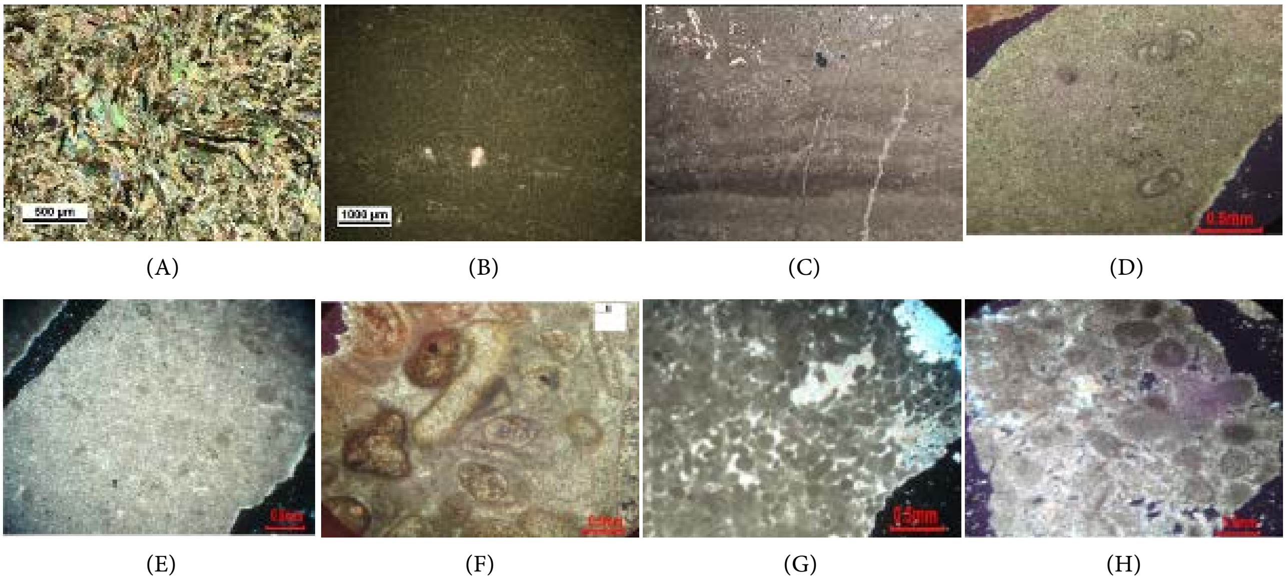
In this research, based on the petrography of thin sections prepared from the studied wells in Qaleh Nar Field, the facies were identified. Microscopic study of carbonate rocks of the Asmari Formation has led to the identification of 10 microfacies in terms of 3 facies association, which include tidal flat (upper tidal and inter-tidal), lagoon and shoal.

5.1. Tidal Flat Facies Association (A)

This facies association includes tidal flat facies which are described in the following.

5.1.1. A1-Anhydrite

This facies mainly composed of anhydrite with finely laminated, or nodular form. The anhydrite in this facies shows mainly chicken wire fabric. This fabric composed of a mosaic of irregular nodules separated by very thin and dark films (remnants) of mudstone or dolomudstone in which nodules grew. The diameter of the nodules varies from few millimeters to centimeters. In thin section, relics of carbonate deposits are present as dark anastomosing stringers and solution seams. Nodular anhydrite are composed of individual nodules with >0.5 cm to 2 cm scattered in the matrix. Nodules are oval, spherical, and amorphous in shape. There are no fossils and sedimentary structures in this facies. In thin section sample, anhydrite crystals are lath in shape with parallel, subparallel and accidental orientation (Figure 3(A)) Anhydrite facies in these units are associated with stromatolite bindstone and dolomudstone and other peritidal facies. Anhydrites are mostly tights and impermeable.



(A) (B) (C) (D)

(E) (F) (G) (H)

Figure 3. Facies identified in the studied interval. (A) Anhydrite (A1). (B) Dolomudstone (A2). (C) Stromatolite bindstone (A3). (D) Fossiliferous mudstone to bioclast wackestone (B1). (E) Peloid wackestone (B2). (F) Bioclast wackestone to packstone (B3). (G) Peloid grainstone (C1). (H) Ooid peloid grainstone (C2). All photos in polarized light.

Interpretation

Anhydrite layers associated with nodular, chicken wire fabrics in transition with tidal flat deposits developed definitely in the supratidal (sabkha-type) and salina settings of carbonate platforms particularly during arid climate conditions [44] [45] [46] [47]. These facies may also result from extensive anhydrite replacement of previously carbonates deposits, but of later diagenetic origin. These are distinguished by their overprinting nature cross-cutting both sedimentary and stratigraphic fabrics.

5.1.2. A2-Mudstone/Dolomudstone

This facies consists of mudstone or dolomudstone (**Figure 3(B)**) with anhydrite nodules, fenestral fabric, bird's eye and mud cracks. No fossils and allochems was identified in it. This microfacies is associated with anhydrite layer (A1) and stromatolite bindstone (A3) of tidal flat setting. They are found capping shallowing upward sequences. Fenestral pores and bird's eye are commonly filled by anhydrite cements. Sometimes aggrading neomorphism causes to form planar-e and planars dolomicrosparite and dolosparite crystals in dolomudstone.

Interpretation

Based on the evidence like mudstone texture along with anhydrite nodule, fenestral fabric, birds eye, mud cracks this facies was deposited in the arid supratidal (sabkha) to upper intertidal or protected low-energy setting in this area.

5.1.3. A3-Stromatolite Bindstone

This microfacies consist of stromatolite bindstone with microbial filaments, anhydrite nodules, and anhydrite needles. Lamination is one of the prominent features in tidal facies that indicates the periodicity of sedimentation process and microbial function (cover of blue-green algae). They are trapped in the cohesive microbial mat (biofilm) during deposition [48]. They can also contain small mud cracks (originating from bedding surfaces) and minor exposure surfaces. A3 is mostly observed in association with A1 and A2 (**Figure 3(C)**).

Interpretation

Microbial carbonates such as stromatolites bindstone (A3) are biosedimentary structures in carbonates that form by calcified microbe colonies [40]. Stromatolites tend to be better developed in microbial mud flats in the higher parts of the intertidal area, which is less favorable for other organisms that may graze on the mats. These microbial mud flats facies are generally deposited in non-saline, low energy, protected flats and tend to dominate the upper parts of the high order regressive-half cycles, eventually capped by sabkhas or erosive surfaces. Some of these facies are interpreted as intertidal muds associated with microbial filaments but have the other features and textures associated with the upper intertidal zone. In some places these thin intertidal stromatolites can be intercalated at a fine scale with grainier beds. They are basically fine-scale interbeds of intertidal sands, microbial mud flats and intertidal muds facies.

5.2. Lagoon Facies Association (B)

This facies association consists of the following facies:

5.2.1. B1-Fossiliferous Mudstone to Bioclast Wackestone

The facies is mainly characterized by mud-supported facies. The main allochems present in this microfacies are skeletal debris including shell fragments, gastropod and small foraminifera scattered in the matrix and peloid (**Figure 3(D)**). Various types of vertical, oblique and horizontal burrows are presents. In microscopic scale this facies exhibits a mottled appearance that created by bioturbation and trace fossils. The rate of bioturbation is notable in this facies, due to probable reducing the rate of sedimentation.

Interpretation

Based on observational criteria and their sedimentological context this facies is deposited on the low-energy shallow lagoonal environment [40].

5.2.2. B2-Peloid Wackestone

This facies consist of more than 10% of non-skeletal allochems including peloids and has a muddy matrix and about 2% of anhydrite is found in it. Scattered bivalve debris and shell fragments are also present (**Figure 3(E)**).

Interpretation

Minor amount of skeletal debris along with muddy texture indicates that B2 was deposition in low-energy shallow subtidal and lagoonal setting.

5.2.3. B3-Bioclast Wackestone to Packstone

Skeletal grains are the main allochems in this facies. They often contain significant amounts of peloid, fecal pellet, gastropod, bivalve debris, Ostracod, algae and benthic foraminifera (e.g. Miliolids). Most of the bioclast debris are micritized. Bioturbation in the form of borrowings are present (**Figure 3(F)**).

Interpretation

This facies with high amounts of gastropod, mollusk, foraminifera and algae and associated with peloidal features, and presence of abundant carbonate mud are interpreted as a low to medium energy lagoonal setting. Mud and peloids are common in modern lagoons that form behind shoals and reefal barriers [49] [50] [51]. Bioclasts such as lagoonal microfauna, benthic foraminifera and mollusk debris derived mainly from gastropods and bivalves are characteristic grains of lagoons. Micritized grains represent the deposition in the photic zone on its sedimentary substrate. The occurrence of low-energy indicators such as micropeloids, high-mud content and low-diversity fossil assemblage suggests that deposition took place in protected restricted lagoon settings.

5.3. Shoal Facies Association (C)

5.3.1. C1-Peloid Grainstone

The main allochem in this facies with grainstone texture is fine-grained peloid (40%). Rounded intraclasts and micritized bioclasts are subordinates (**Figure 3(G)**). Peloids are oval and occasionally elliptical. The allochems are mostly well-sorted. There are dominated by early calcite cementation in the form of isopachous rim cement.

Interpretation

Occurrence of peloid and grainstone texture with well-sorting indicate that this facies is deposited in a high-energy shoal environment with significant sediment supply. Shoal bodies are dominant in the high-energy settings of shallow marine environments deposited above the fairweather wave base (FWWB), particularly in an arid climate [42] [49] [52]. These sands were deposited in a host of shoal center to lower intertidal environments from megaripples (often associated with bioclasts) that represent active mobile sand wave-shoal systems to smaller rippled bedforms that may have developed into the intertidal zone (small scale tidal cross-stratification to low angle planar laminations).

5.3.2. C2-Ooid Peloid Grainstone

This facies has a relative high distribution in both calcareous and dolomitic forms. This microfacies is mainly consists of fine-grained peloids (30%) and ooids (20%) with grainstone texture. Allochems are mainly micritized. Locally, skeletal debris is also present (**Figure 3(H)**). Skeletal debris mainly consists of calcareous algae, gastropods, pelecypods and foraminifera. Early calcite cementation in the form of isopachous rim cement is widespread.

Interpretation

Based on the grain size of the allochems, grainstone texture and widespread marine cement it can be concluded that this facies is deposited in a high-energy shoal settings with significant sediment supply. These sands were deposited in a host of shoal margin from large megaripples to dunes that represent active mobile sand wave-shoal systems.

5.4. Depositional Environment

Based on the evaluation of microfacies, 3 distinct depositional settings can be recognized: tidal flat, lagoon, and shoal. The frequency of each microfacies is present in **Figure 4**. According to the description of facies and their variation, comparability of observed facies with carbonate ramp facies, lack of reef facies, abundant oolithic microfacies and wide distribution of tidal flat microfacies indicate these deposits were deposited in a carbonate ramp (**Figure 5**). Likewise, other researcher [14] [15] [16] [18] [20] [21] were studied depositional environment of the Asmari Formation and came in to a similar conclusion.

During the Oligocene and Early Miocene Asmari Formation composed of mixed low energy mudstone, wackestone, packstone together with high energy grainstone. Low energy tidal flat environment involved dolomudstone microfacies with anhydrite nodules. Dolomite crystals are very fine. This two microfacies have precipitated in the inner ramp.

Lagoon setting indicating with mudstone, skeletal wackestone to packstone which was deposited in the inner ramp condition. Foraminiferal assemblages are seen as milliolida families and are the most common allochems in this environment.

High-energy shoal environment was defined with peloid and ooid grainstone. In ooid grainstones, most of the non-skeletal ooids micritized. Ooid grains are formed at high-energy condition but they are micritized in low energy level. These microfacies criteria are developed in the middle ramp. All the identified microfacies and depositional environment are demonstrated in sedimentological log (**Figure 6**).

6. Diagenesis Events

Diagenesis of the Asmari carbonate facies exerts a strong influence on potential reservoir quality. Reservoir rocks appear to have undergone a diagenetic history

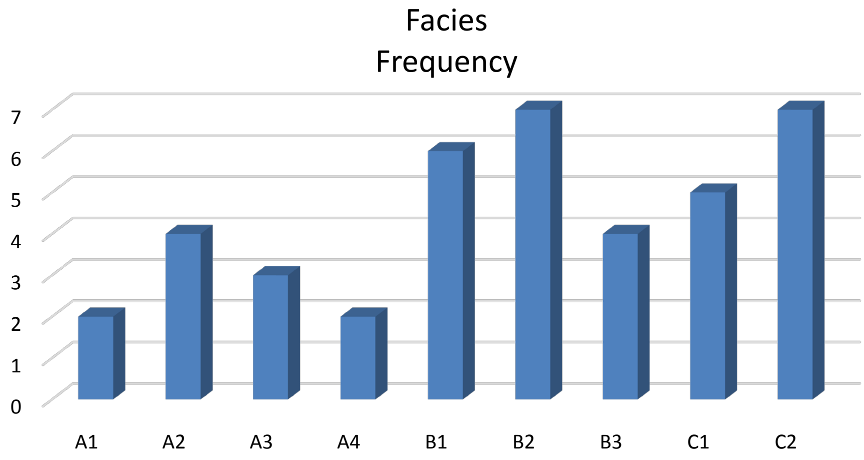
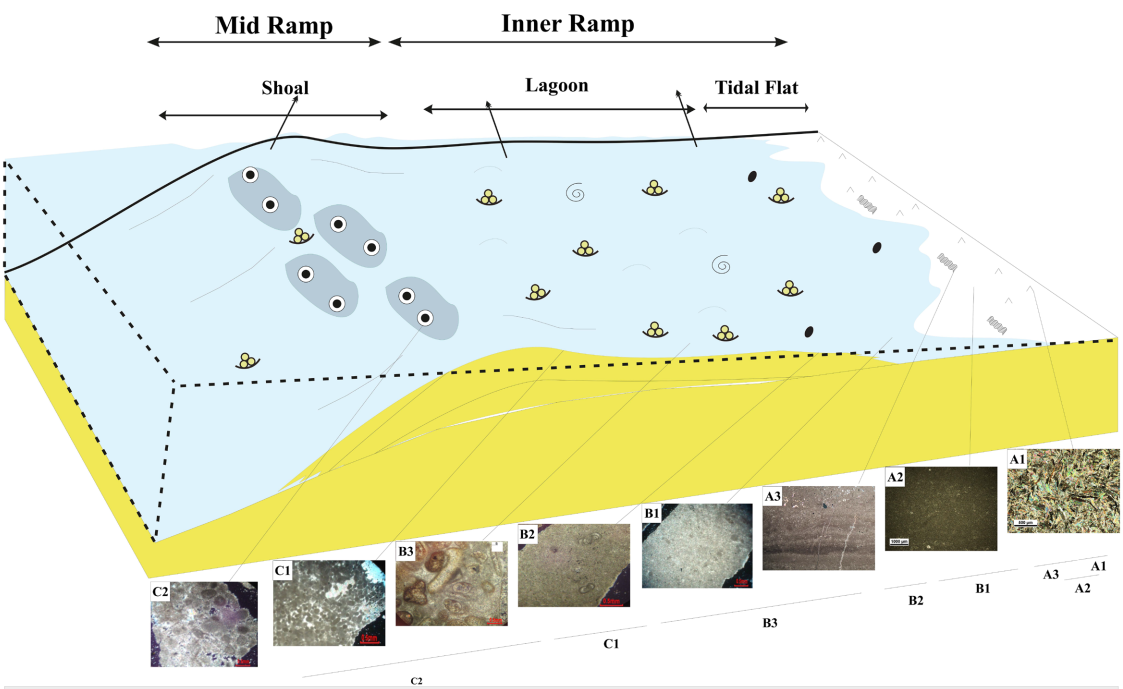


Figure 4. Frequency of each microfacies of the Asmari Formation in Qaleh Nar Field.



LEGEND

Benthic foraminifera	❀	Gastropod debris	@	Shell debris	⌒	Green Algae	⫽
Peloid	●	Ooid	⦿	Stromatholite	≋	Evaporites	^

Microfacies

A1: Anhydrite

A 2: Mudstone/Dolomudstone

A 3: Stromatholite Bindstone

B1: Fossiliferous Mudstone to Bioclast Wackestone

B2: Peloid Wackestone

B3: Bioclast Wackestone to Packstone

C1: Peloid Grainstone

C1: Ooid Peloid Grainstone

Figure 5. Schematic depositional model of Asmari Formation in the study area.

of early marine diagenesis, followed by later meteoric to burial diagenesis. Different diagenetic processes in the Asmari Formation consist of cementation anhydritization, neomorphism, micritization, bioturbation, dissolution, compaction and dolomitization.

6.1. Cementation

One of the important diagenetic processes in the studied interval is cementation, which cause to fill the cavity between the grains or vuggy porosities and caused

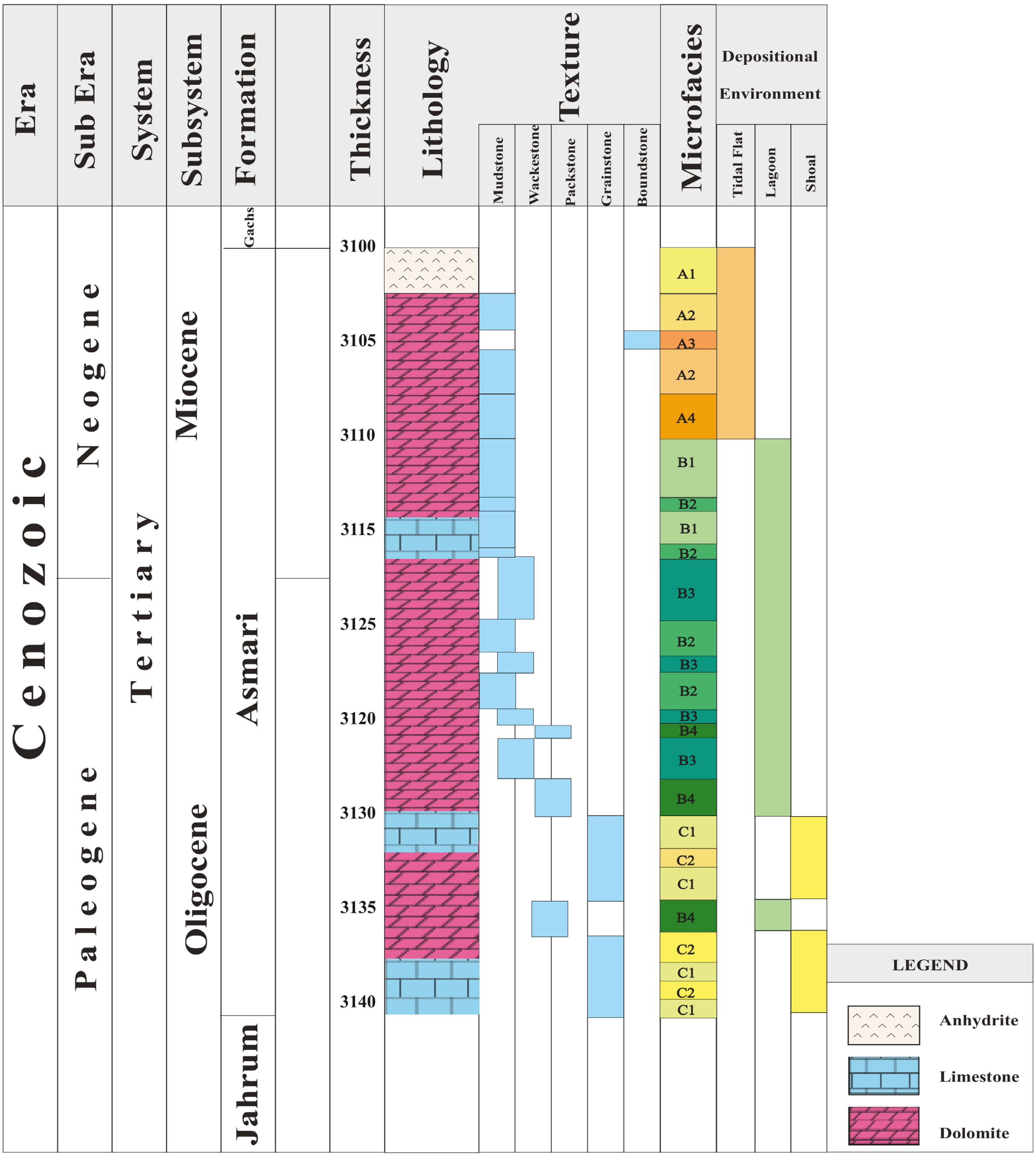


Figure 6. Lithostratigraphy and sedimentological log of the Asmari Formation in the Qaleh Nar Field.

to reduce the porosity. During cementation, the sediments consolidate and are prevented subsequent compaction. Different types of cements identified in the studied interval include isopachous rim cement, equant and mosaic. Carbonate cements can be a good guide in diagnosing their diagenetic environment.

6.1.1. Isopachous Rim Cement

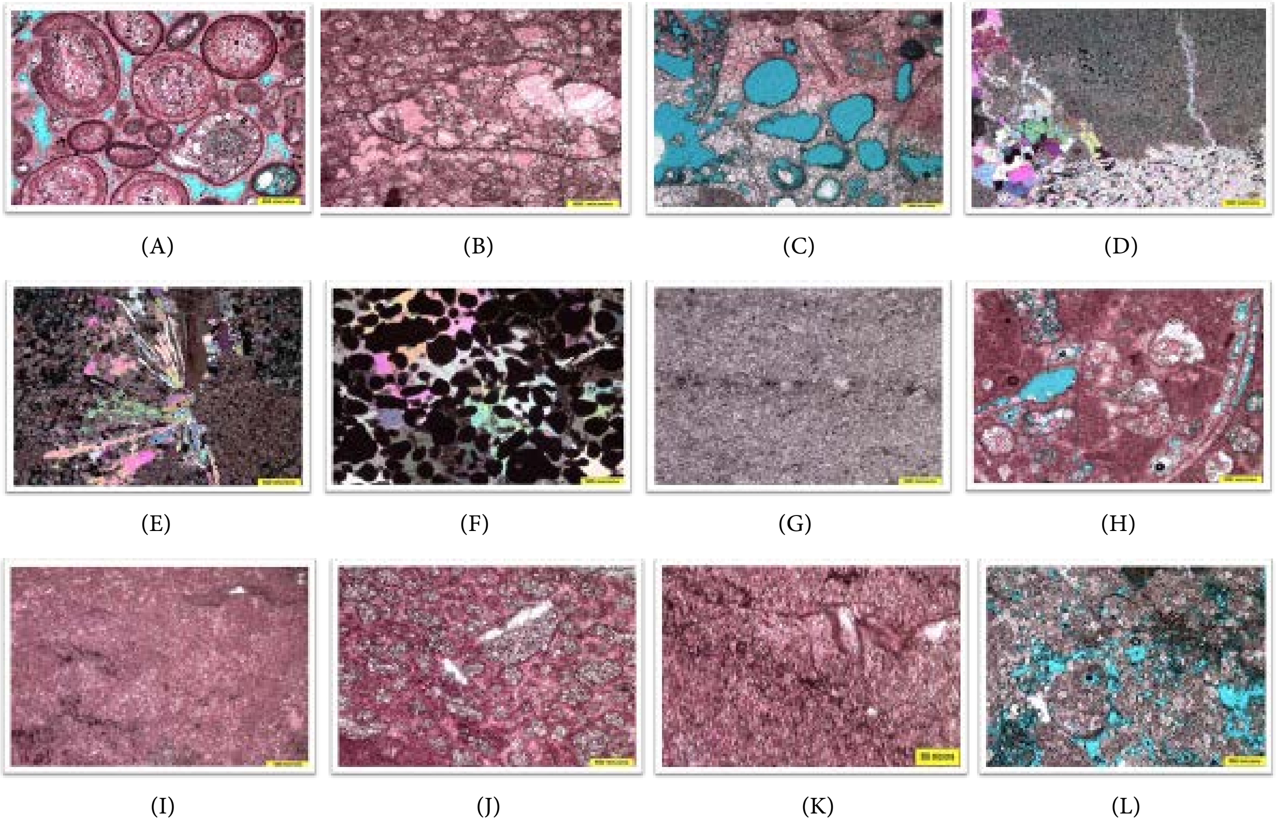
The isopachous calcite cement composed of a layer of nearly uniform thickness around the grain [53] [54]. This type of cement observed in grain-supported fabrics usually forms in the early stages of diagenesis in marine environment (**Figure 7(A)**). It is likely that the original cement mineralogy was formed as fibrous and with aragonitic mineralogy. The presence of rim cements inhibits compaction and tends to preserve porosity. This type of cement formed in marine vadose and phreatic environment [40].

6.1.2. Equant Cement

This cement is composed of clear calcite crystals with approximately equal dimensions. This cement fills the space between the allochems and is mainly found in the bioclast ooid grainstone. In some samples, this cement is present around dolomitized ooids. The crystal size of this type of cement is usually between (35 to 45 microns) and is made of low calcium magnesium (LMC), which is formed both in subaerial and in burial diagenesis [55] (**Figure 7(B)**).

6.1.3. Drusy Calcite Cement

This cements form in the freshwater phreatic zone and also the shallow burial environment with high nucleation rates, and are characterized by crystal sizes which increase towards the centre of a cavity (**Figure 7(C)**) [42] [55]. The mineralogical composition of this cement is low magnesium calcite (LMC) [42].


(A) (B) (C) (D)

(E) (F) (G) (H)

(I) (J) (K) (L)

Figure 7. Diagenetic processes identified in the studied interval. (A) Isopachous rim cement, ppl. (B) Equant Cement, ppl. (C) Drusy calcite cement, ppl. (D) Acicular to fibrous (yellow arrow), equant to mosaic (red arrow), xpl. (E) Needle anhydrite, xpl. (F) Poikilotopic anhydrite cement, xpl. (G) Neomorphism in dolomitcrite, ppl. (H) Micritization, ppl. (I) Bioturbation, ppl. (J) Partial dolomitization of ooids, ppl. (K) Solution seam in fabric destructive dolomitization, ppl. (L) Dissolution, ppl.

Due to the dissolution of some grains (e.g. bivalves, molluscs and gastropods), secondary porosities are filled with this type of cement [42].

6.2. Anhydritization

Various structures and textures of anhydrite have been observed in the studied interval. The main anhydrite textures are acicular to fibrous (**Figure 7(D)**, yellow arrow), equant to mosaic (**Figure 7(D)**, red arrow) and needle shape (**Figure 7(E)**). Poikilotopic (**Figure 7(F)**) cement with replacement and fracture filling anhydrite are accounted as the most common diagenetic features in anhydrites of studied interval. Evaluation of anhydrite occurrences and features supported both primary and secondary formations. The nodular to chicken-wire anhydrite formed under synsedimentary sabkha condition, whereas anhydrite cements occurred during the late stages of diagenesis (shallow burial stage). Anhydrite fabric imposed a significant control on the reservoir quality of the Asmari carbonates at the Qaleh Nar Field.

6.3. Neomorphism

The term neomorphism was first introduced by Folk (1965) [45] to cover processes related to transformations of minerals taking places in the presence of water through dissolution, reprecipitation processes between one mineral and itself or polymorph and recrystallization. A common neomorphic process in the Asmari Formation is aggrading neomorphism or recrystallization in which the crystal size increases (**Figure 7(G)**). During this process fine crystal mosaics of microcrystalline calcites are replaced by coarser crystal mosaics of the same mineral or its polymorph. This process occurred in the tidal facies of this formation and the size of the crystals increased from 4 microns to about 20 microns. Neomorphism mostly forms in the freshwater phreatic zone and sedimentary structures are preserved during it [40] [55].

6.4. Micritization

Micritization is a process caused by alteration and destruction of skeletal and non-skeletal debris. In this process, allochems are altered by algae, fungi and bacteria. The samples studied in Asmari Formation that have been affected by this process have been completely micritized, which may indicate the intense activity of organisms (**Figure 7(H)**). In the studied samples, micritized grains can be distinguished from fecal pellets due to their irregular shapes [42]. This process takes place in the marine phreatic environment [56].

6.5. Bioturbation

This process is performed immediately after deposition on soft sediments. This process is one of the prominent features of the lower intertidal regions and is mostly formed in the marine phreatic environment. One of the causes of this process is the activity of digging organisms and plant roots. Its effects include in-situ modification of the texture of sediments, packing, sorting and clay content, fabrics, and displacement of microorganisms and non-living particles and can result in complete disorganization of deposits. The common criteria of bioturbated limestones are a mottled appearance differing in color and texture. This process is mostly observed in mudstone of intertidal setting (**Figure 7(I)**).

6.6. Dolomitization

Different types of dolomite observed in the studied interval which are described in the following

6.6.1. Dolomicrite

Based on petrographic investigation this kind of dolomite consists of very fine to fine, unimodal, anhedral crystals of dolomite. The size of dolomite is between 5 - 16 μ (**Figure 7(G)**). This texture is equivalent to xenotopic-A [57] and nonplanar-A [58]. Some features like fenestral fabrics, microbial filaments, evaporitic cast and anhydrite nodules are also present.

6.6.2. Dolomitization in Grain-Supported Facies

Dolomitization in grain-supported facies can be observed in two manners: partial and complete dolomitization.

1) Partial Dolomitization

In some grain-supported facies dolomitization is partial and fabric selective. In ooid grainstone, allochems like ooid are selectively replaced by dolomite, while the matrix remains limy (**Figure 7(J)**).

2) Complete Dolomitization

In this type of dolomitization both allochems and matrix were replaced by dolomite. Complete dolomitization in the studied interval occurred in two forms including fabric-retentive and fabric-destructive.

1) Fabric-retentive: these dolomites are characterized by microcrystalline to finely crystalline subhedral to anhedral crystals. Dolomitization occur mimetically and precursor fabrics and fine-scale depositional structures like lamination and bioturbation and even internal structure of ooids are well-preserved (**Figure 7(A)**).

2) Fabric-destructive: this type of dolomite consists of fine to coarse euhedral to subhedral crystals which replaced the precursor limestone and almost completely obliterate the precursor limestone textures (**Figure 7(K)**).

6.7. Compaction

Compaction in the Asmari Formation is due to mechanical and chemical processes and ordinary depending of the overburden pressure (Mechanical compaction by means of grain resistance in grain supported facies. Stylolites and solution seams are the products of chemical compaction. These features are observed thin sections (**Figure 3(E)**). They are in form of low amplitudes developed locally in the studied interval. They are mostly oil stained and it seems that these are acting as a passage for hydrocarbons (**Figure 7(K)**).

6.8. Dissolution

This process has led to generation of different types of secondary porosity especially moldic and vuggy porosity in the studied interval (**Figure 7(L)**). Distribution of this process is pervasive in some intervals. Undersaturation of pore fluids with respect to carbonate leads to dissolution of metastable carbonate grains and cements. Dissolution is particularly effective in shallow near-surface meteoric environments (phreatic zone) where seawater becomes undersaturated with respect to aragonite and Mg-calcite [40] [55]. Unstable mineral like aragonite are frequently dissolved leaving behind a moldic pore in the shape of the original allochems.

6.9. Paragenetic Sequence

Diagenetic processes in three diagenetic environments (marine, meteoric and burial) affected the samples. This diagram showed relative time of different processes (**Table 1**).

7. Porosity

In the studied interval of the Asmari Formation, primary and secondary porosities have been identified based on Choquette and Pray classification [59]. The main identified porosity types are interparticle porosity (**Figure 8(A)** and **Figure 8(B)**), intercrystalline porosity (**Figure 8(C)**) and moldic (**Figure 8(D)**),

Table 1. Paragenetic sequence of diagenetic processes in the Asmari Formation.

Diagenetic Process	Digenetic Environments		
	Early		Late
	Marine	Meteoric	Burial
Bioturbation	———		
Micritization	———		
Isopachous cement	———		
Equant Cement	———	- - - - - - - - - -	
Dolomicrite	———		
Mechanical Compaction			———
Neomorphism		- - - - ———	
Dissolution		———	
Spary calcite cement			———
Chemical Compaction			———
Anhydrite Cement			———

Increasing time and depth of burial →

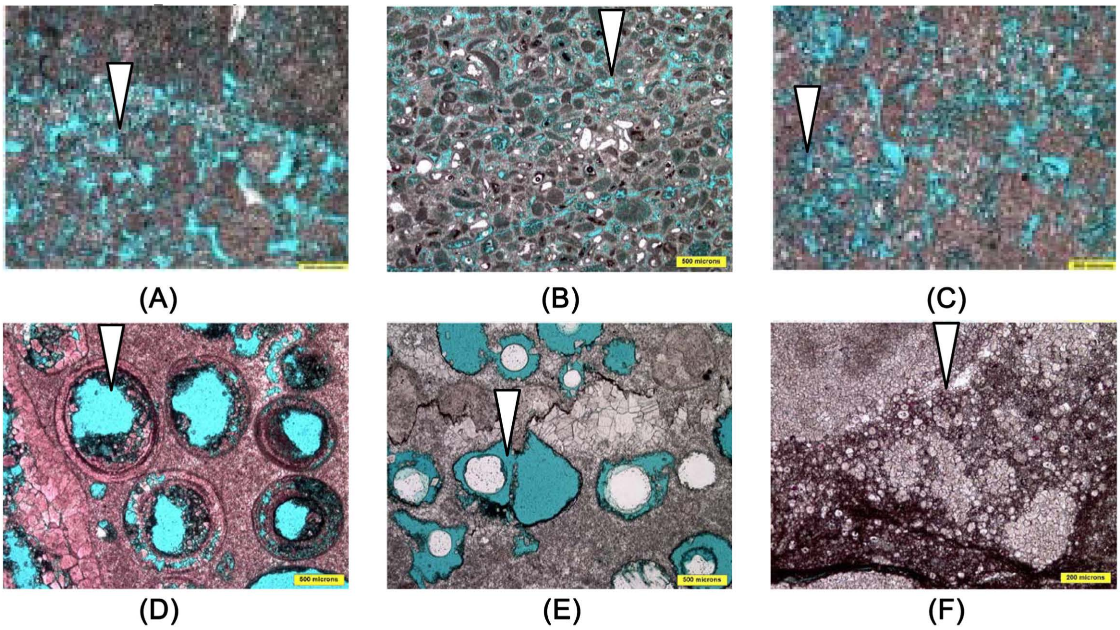


Figure 8. Porosity types identified in the studied interval. (A) and (B) Interparticle porosity, ppl. (C) Intercrystalline porosity, ppl. (D) Moldic porosity resulting from dissolution of ooids, ppl. (E) Vuggy porosity, ppl. (F) Fracture porosity, ppl (samples are impregnated with blue epoxy).

vuggy (**Figure 8(E)**) and fracture porosity (**Figure 8(F)**). Based on the Ahr classification of porosity in carbonate rocks [4], porosity in the Asmari Formation depositional and diagenetic processes and fracturing make role on reservoir characterization. Interparticle porosity in grainstones of shoal setting was formed during depositional process. Tow diagenetic events have positive role in forming porosity, including dissolution by forming vuggy and moldic porosities and dolomitization by forming intercrystalline porosity. Although cementation, anhydritization and compaction have negative effect on reservoir quality. Fracturing is another process which has an important role in improving reservoir quality.

8. Conclusions

The study of thin sections of Asmari Formation in the studied well in Qaleh Nar field shows that the formation is composed of a period of dolomitic and carbonate rocks. Based on petrographic analysis, 10 microfacies have been identified. The facies classification and interpretation are based on facies characteristics, stratigraphic positioning and context, types of sedimentary processes involved in facies genesis and fauna content. These facies have been interpreted in terms of 3 depositional environments including: tidal flat (A), lagoon (B) and shoal (C). The lack of great barrier reefal microfacies and turbidites, abundant oolithic microfacies, wide distribution of tidal flat and gradual facies change indicts that the Asmari Formation in the studied area was deposited in a carbonate homoclinal ramp in an arid climate with different subenvironments including inner, mid and outer parts. Sedimentological studies indicate that different diagenetic processes have been affected on the studied interval including cementation, anhydritization, neomorphism, micritization, bioturbation, dissolution, compaction and dolomitization. These processed have been occurred in three diagenetic environments including marine, meteoric and burial.

Diagenetic processes involved in the Asmari Formation were responsible for the modification of reservoir quality. Dissolution, fracturing and dolomitization have positive effect on reservoir quality while anhydritization, cementation and compaction have negative effect on it. The main identified porosity types are interparticle, intercrystalline and moldic, vuggy and fracture porosity. So, porosity in the Asmari Formation is the products of depositional and diagenetic processes and fracturing.

Declarations

1) Did you or your institution at any time receive payment or services from a third party (government, commercial, private foundation, etc.) for any aspect of the submitted work (including but not limited to grants, data monitoring board, study design, manuscript preparation, statistical analysis, etc.)? Yes [ ] No [√]

2) Do you have any patents, whether planned, pending or issued, broadly relevant to the work? Yes [ ] No [√]

3) Are there any other potential conflicts or relevant competing interests that should be known by the Editor? Yes [ ] No [√]

4) Are there other relationships or activities that readers could perceive to have influenced, or that give the appearance of potentially influencing, what you wrote in the submitted work? Yes [ ] No [√]

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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