Geopersia 2021, 11(1): 219-243
DOI: 10.22059/GEOPE.2020.309894.648576

RESEARCH PAPER

Depositional and diagenetic impact on reservoir quality of the Asmari carbonate reservoir, SW Iran

Abdolmotalab Haghighat, Mohsen Aleali *, Nader K. Ghadimvand, Davood Jahani, Zahra Maleki

Department of earth sciences, Science and Research Branch, Islamic Azad University, Tehran, Iran

Received: 12 September 2020, Revised: 01 November 2020, Accepted: 4 November 2020

Abstract
The Oligo-Miocene Asmari Formation is the most prolific reservoir in the Dezful Embayment, south-west of Iran. Depositional and diagenetic effects on reservoir quality in the sequence stratigraphic framework were carried out on the basis of petrographic investigation, petrophysical logs, and core measurement porosity and permeability data. Petrographic analysis resulted in the identification of 12 microfacies classified in 5 sub-environments including tidal flat, lagoon, barrier, shallow open marine and basin, which indicate deposition in a homoclinal ramp setting. Tidal flat, lagoonal and barrier microfacies are mostly present in the upper and middle parts of the Asmari Formation, while outer ramp microfacies largely developed in the middle part. Anhydrite and calcite cementation, compaction, dolomitization, dissolution, and fracturing are the main diagenetic controlling factors on petrophysical properties. Fracturing, dolomitization, and dissolution are contributed to reservoir quality enhancement, while compaction and cementation had negative effects on reservoir quality. The studied successions are represented by 3 third-order sequences of early Aquitanian, late Aquitanian and early Burdigalian ages that largely deposited in the highstand systems tract (HST) stage.

Keywords: Asmari Formation; Dezful Embayment; Microfacies, Diagenesis, Reservoir Quality.

Introduction

Carbonate reservoirs are more complicated than clastic reservoirs (Ahr, 2008). Petrophysical properties in carbonate rocks are affected by depositional geometry, lithological variation and diagenetic modifications (Lucia, 2007 & Ahr, 2008). Depositional facies is dictated by carbonate platform geometry that, in turn, controls the diagenetic regime (Ehrenberg et al., 2007). Relative sea-level variations and sequence stratigraphic framework affect carbonate platform geometry (Hollis & Sharp, 2011). Herein, we attempt to obtain an improved comprehension of carbonate reservoir heterogeneities of the Asmari Fm. to propose the sequence stratigraphic framework for further reservoir quality assessment. The Oligo-Miocene Asmari deposits in the Zagros area are among the well-known hydrocarbon producing intervals in the world. This formation has the most thickness in the Dezful Embayment (e.g. Alavi, 2004). These carbonate platform successions comprise giant and supergiant reservoir fields in SW Iran and NE Iraq. Comprehensive lithostratigraphic and microfacies studies of Asmari Formation have been conducted by James and Wynd (1965) and Sampo (1969), respectively. Recently, numerous works have been published on the Asmari Formation, but many of them of a more local nature. These works focused on biostratigraphy (Seyrafian & Hamedani, 2003), depositional environment (Vaziri- Moghaddam et al., 2006), diagenesis (Aqrawi et al., 2006),

* Corresponding author e-mail: aleali.mohsen@gmail.com

isotopic dating (Ehrenberg et al., 2007; Mossadegh et al., 2009), reservoir rock typing (Moradi et al., 2017; Farshi et al., 2018), and sequence stratigraphy (Avarjani et al., 2015; Daraei et al., 2017). Despite all these studies, lack of a study linking reservoir quality to the depositional environment and diagenetic features especially in the study area is felt. Regarding that, the main purposes of this research are: to define facies types and depositional setting of the Asmari Formation, to determine the major diagenetic imprints and their effects on reservoir quality, and correlate the diagenetic trends in the studied field within the framework of sequence stratigraphy.

Geological context

The Zagros Mountains resulted from the multi-phase collision of the Arabian shield with the Iranian microplate (Berberian & King, 1981; Sepehr & Cosgrove, 2004). It is divided to imbricated thrust zone, and folded belt (Sherkati & Letouzey, 2004) (Fig. 1). The folded belt is marked by asymmetrical anticlines with NW-SE trends, and includes Dezful and Kirkuk Embayments, Lurestan, Izeh, Abadan Plain and Bandar Abbas hinterland (Fig. 1) (Sepehr & Cosgrove, 2004). Dezful Embayment is considered as a part of the Zagros fore-deep that is limited to the Kazerun fault to the east, and Balarud flexural zone to the north. This area consists of 15 km thick sediments from Paleozoic to recent (Motiei, 1993).

The Oligo-Miocene Asmari Formation overlies the Pabdeh shale, and is overlain by the Gachsaran evaporites (Fig. 2). It is well-developed throughout the Zagros area unless the Bandar Abbas region. In the late Oligocene, north parts of Lurestan and Fars were exposed, but the Ahwaz sandstone member was deposited in the Khuzestan area (Dezful Embayment).

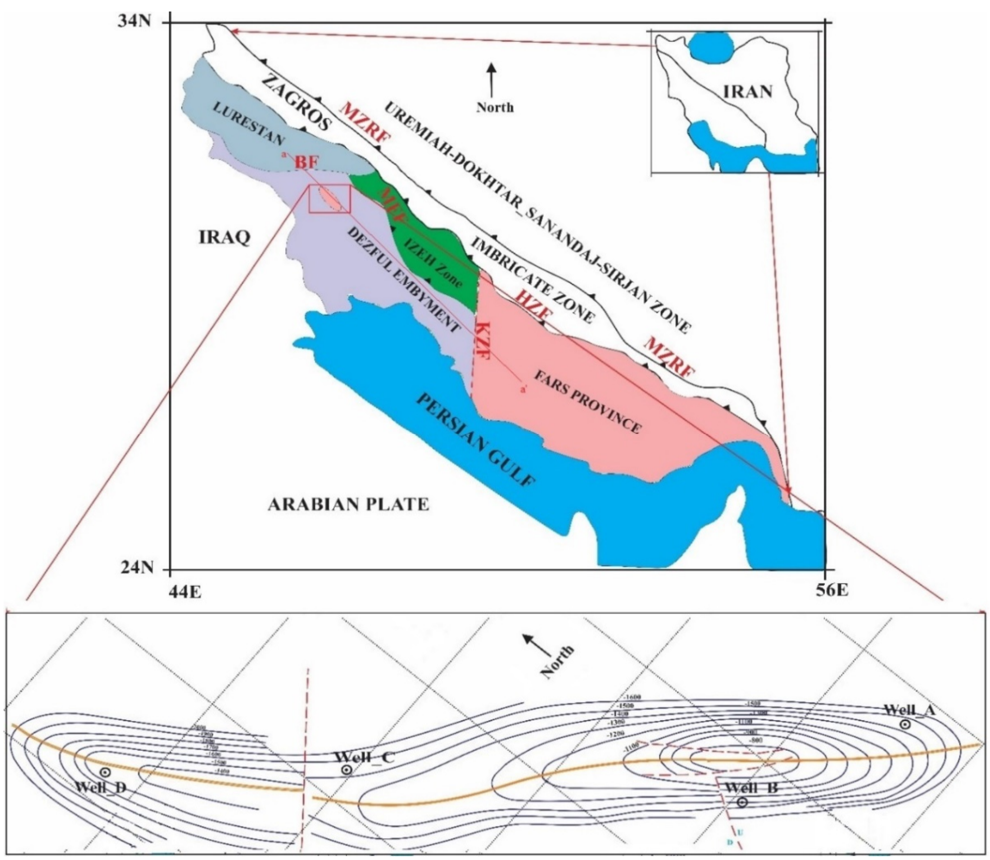

Figure 1. Main structural subdivisions of the Simply Folded Zagros Belt (Alavi, 2004). The studied oil-field is located in Dezful Embayment

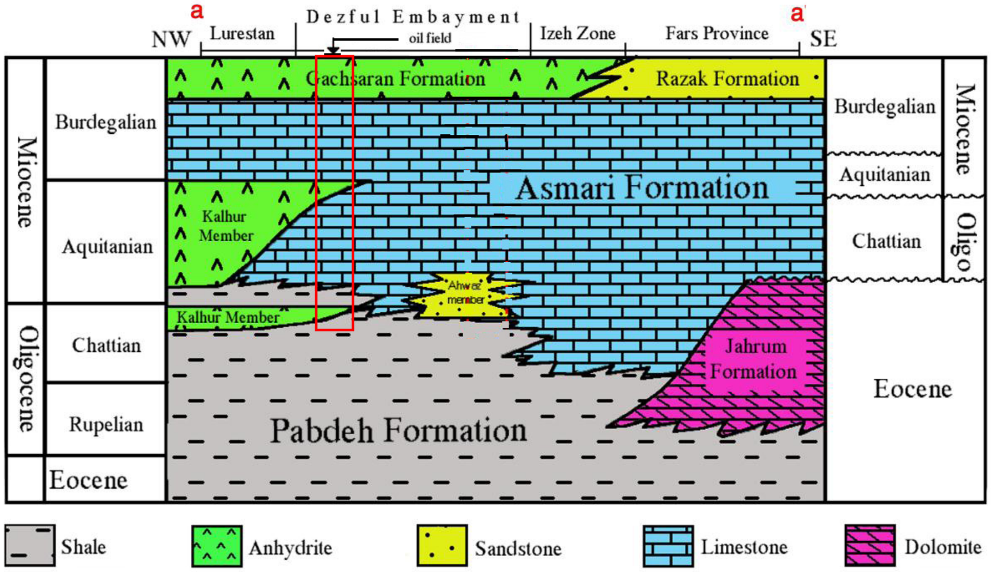

Figure 2. The Oligo-Miocene wheeler diagram of the Dezful Embayment shows a complex sedimentary system along with large variable lithologies (e.g., sandstones, marls, carbonates and anhydrites) and depositional geometries (modified from van Buchem et al., 2010 and). (The figure is cross section a-a' in Fig. 1a)

Simultaneously, the Kalhur evaporitic member, as a part of the middle Asmari, was deposited in the Lurestan Province. In the Aquitanian stage, shallowing-upward cycles of the middle Asmari Formation were deposited throughout the basin. By the end of this depositional cycle, the shallow water condition was developed leading to the dolomitization of the middle Asmari sequences (Aghanabati, 2004 & van Buchem et al., 2010). Subsequently, through the widespread transgression of the Burdigalian Sea, the upper Asmari sequence has been deposited, and at the end of the Burdigalin stage, the Asmari depositional cycle was terminated due to the significant sea-level dropping stage. As a consequence, the dominant evaporative condition was governed over the basin (Aghanabati, 2004).

The studied field is an NW-SE anticline, which is placed in the northeastern Dezful Embayment (the Central Zagros Basin) (Fig. 1). The Asmari Formation is considered as a key reservoir in the field. In this field, the Asmari mainly contains carbonate-evaporite facies, and the lower part of the Asmari (equivalents to the sequences 1 to 3 of van Buchem et al., 2010) has not been deposited. Basal anhydrite of the Asmari Formation overlaid directly the Pabdeh marls, and the Gachsaran cap rock, conformably overlaid the Asmari carbonates (Fig. 2).

Materials and methods

Data from four exploration wells from one of the oilfield in the Dezful Embayment, northeast of Ahwaz City has been collected for this research (Fig. 1). The Asmari Formation has a different thickness between 280 m (well C) and 350 m (well A). Close sampling and high-resolution microscopic studies (4872 thin sections from four wells; Well A, 1472 samples; Well B, 1400 samples; Well C, 800 samples and Well D, 1200 samples) are conducted to define main depositional microfacies of the formation. Some thin sections were stained with Alizarin Red-S through standard approach (Dickson, 1965), among which 400 samples were also impregnated by blue-dyed resin to examine pore space properties. Facies nomenclature was done according to a modified Dunham (1962) classification along with diagnostic allochems, mineralogical composition, and grain size. More detailed facies analysis was conducted based on standard microfacies schemes (e.g., Flügel, 2004). A schematic depositional model was proposed for the Asmari Formation in the study area and the effect of facies distribution on reservoir quality development was discussed.

Porosity and permeability from cores of two wells (B and D) including 1300 core porosity – permeability along with wireline logs of four wells (A, B, C, and D) were also available for this study. The main sequences and startal surfaces were recognized based on microfacies properties, their sedimentary environment and deepening and shallowing trends in the microfacies vertical arrangement. Identification of the sequences was based on (van Wagoner et al., 1990; Vail, 1990), where each sequence is restricted between two sequence boundaries in the lower and upper part and maximum flooding surface (MFS) distinct transgressive systems tract (TST) from high stand systems tract (HST). Finally, the relationship between recognized sequences and systems tract with petrophysical properties (porosity and permeability) and how the reservoir quality changes during its deposition is determined.

Results

Facies Analysis

Results from petrographic investigation allowed the recognition of 12 microfacies, which were classified into five facies belts. The main characteristics and their depositional setting of the recognized microfacies are represented in Table 1 and Figure 3.

Anhydrite (MF1): It is observed as chicken-wire structure, parallel lamination and coalesced nodules (Fig. 4-A) and occurs in two horizons (Kalhor Member and Gachsaran Formation). It plays the role of a seal for the studied interval of the Asmari Formation. The anhydrite probably precipitated in a hypersaline lagoon/ sabkha environment (e.g., Alsharhan & Kendall, 1986; Lucia, 2007). The existence of supratidal evaporates and anhydrites indicates that the facies was deposited in an arid and warm climate (Flügel, 2004) (Table 1).

Anhydrite bearing mudstone (MF2): The major components include fossil fragments of gastropod, miliolid, rotaliids, and echinoid (Fig. 4-B). Scattered anhydrite patches are observed in pore-filling and nodule forms. Its sedimentological nature indicates a supratidal to intertidal setting affected by hypersaline waters (Flügel, 2004) (Table 1).

Dolomudstone (MF3): The facies has not any observable allochems (Fig. 4-C). Dolomite crystals are identified with types of non-planar to planar-s textures. Microbial and fenestral fabrics are also observed in this facies. Anhydrite nodules are present (Fig. 4-C). The main porosities include fenestral, intercrystalline and interparticle pores.

Quartz-bearing wackestone (MF4): It contains sand-sized quartz grains within a micrite matrix (Fig. 4-D). The quartz grain is possibly deposited during the lowstand levels of the basin through windy currents. Fossil contents such as some benthic foraminifera, gastropods, and ostracods indicate a low energy shallow-marine setting (Flügel, 2004) (Table 1).

Echinoid wackestone (MF5): The major constituents include echinoids and rotaliids as well as other fossil fragments of benthic foraminifera (Fig. 4-E). This facies can be attributed to the low energy setting of a lagoonal condition (Flügel, 2004) (Table 1).

Benthic foraminifera wacke to packstone (MF6): Benthic foraminifera including miliolids, *Peneroplis* sp., *Borelis melo curdica*, *Dendritina* sp., and *Archias* sp. constitute the main skeletal grains of this microfacies (Fig. 4-F). The presence of fossil content and characteristics of this facies reveal the restricted lagoon setting (Flügel, 2004) (Table 1).

Peloidal wacke to packstone (MF7): It mainly contains peloids, some fragments of miliolids, ostracods, and quartz grains (Fig. 5-A). Its depositional condition can be assigned to shallow and medium energy part of the lagoonal setting (Flügel, 2004) (Table 1).

Benthic foraminifera packstone to grainstone (MF8): The mainly contains benthic foraminifera and minor constituents such as peloid, gastropod and algal fragments (Fig. 5-B).

Abundance of benthic foraminifera and medium sorting of grains indicate relative reworking of allochems and their deposition in a shallow high energy condition of back-shoal to the proximal of the middle ramp setting (Flügel, 2004) (Table 1).

Coral boundstone (MF9): The major skeletal components are coral, and some bryozoan along with echinoid fragments (Fig 5-C). The occurrence of this facies is to appear mainly as a patch reefs in the studied field. The depositional setting of these reef bodies can be assigned to the distal part of the inner ramp (Flügel, 2004) (Table 1).

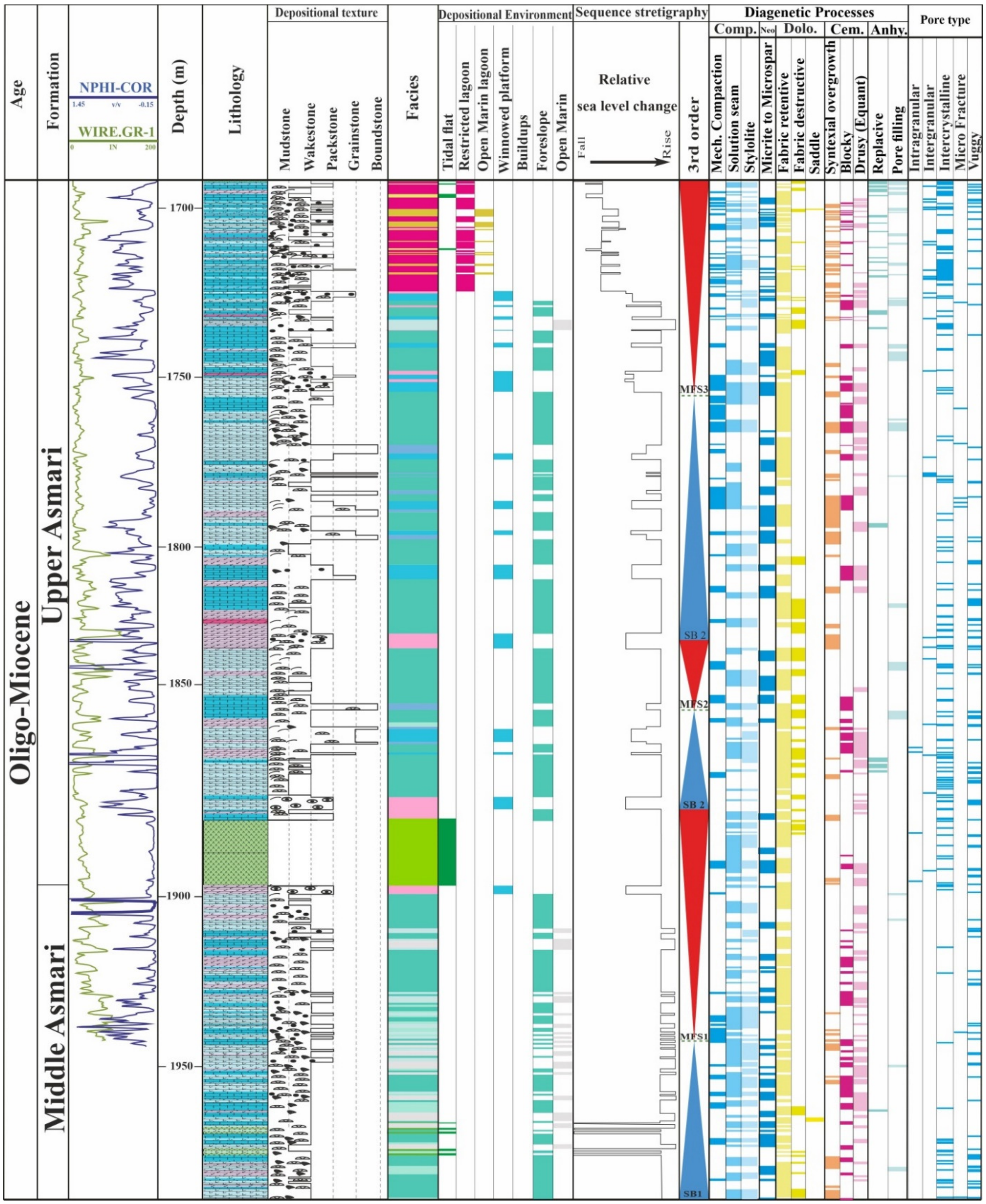

Figure 3. Lithology, log response, sedimentary facies, identified sequence and diagenetic features of the well B in the studied field

Table 1. Main recognized microfacies of the Asmari succession in the studied oil field

Microfacies	Code	Main Allochems	Facies belt
Massive Anhydrite	MF1	-	Supratidal
Anhydrite bearing mudstone	MF2	gastropod, benthic forams, echinoid	Supratidal to intertidal
Dolomudstone	MF3	-	Intertidal
Quartz-bearing wackestone	MF4	Gastropod, ostracod, miliolid	Lagoon
Echinoid wackestone	MF5	Echinoid, miliolid, textularia, red algea fragments	Lagoon
Benthic frominifera wacke to packstone	MF6	Benthic forams (miliolid, *Borelis*, *Peneroplis*, *Dendritina rangi*), ostracod	Restricted lagoon
Peloidal wacke to packstone	MF7	Peloid, miliolid, ostracod	Lagoon
Benthic frominifera pack to grainstone	MF8	Peloid, benthic foraminifera, gastropod	Leeward shoal
Coral boundstone	MF9	Coral	Shoal
Algal wackestone	MF10	Coralline algal, bivalve, gastropod	Middle ramp
Faverina packstone	MF11	*Faverina*, peloid	Open marine
Planktonic foraminifera wacke to mudstone	MF12	*Globigerinids, Ditrupa*	basin

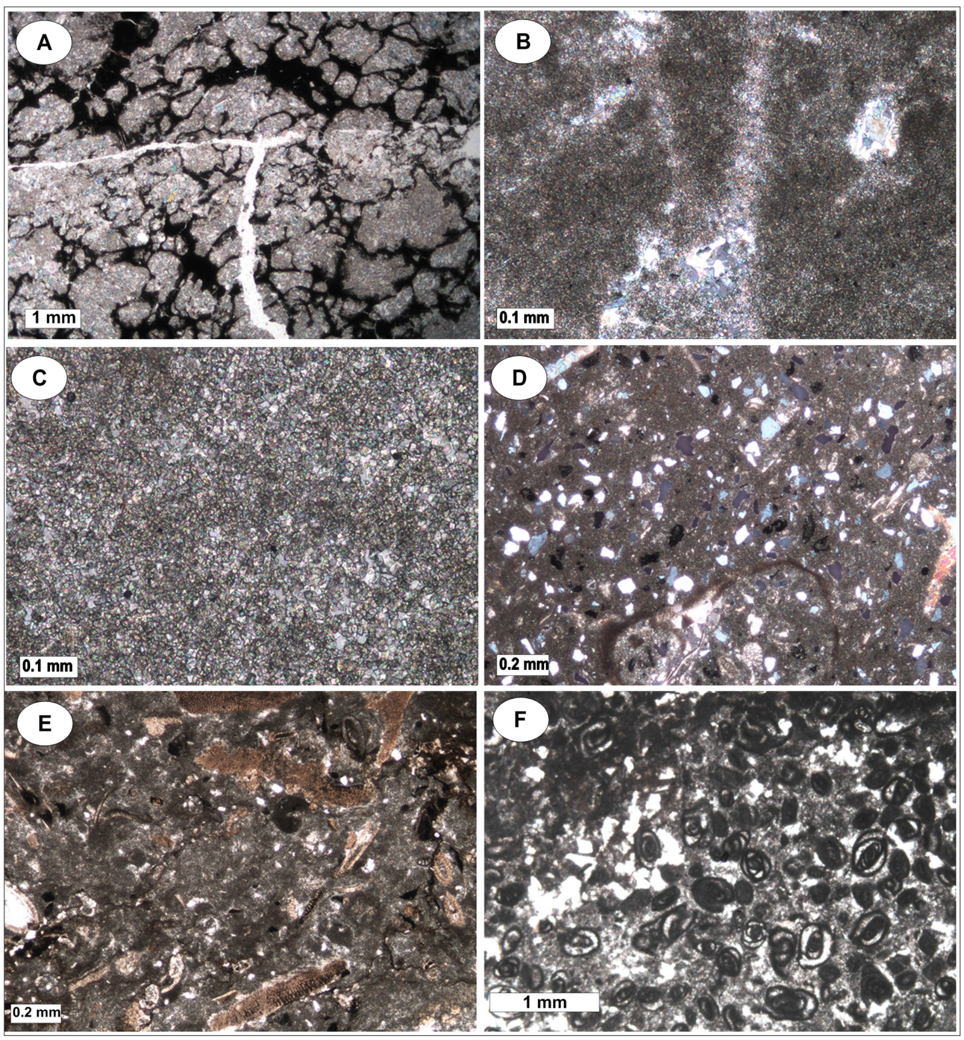

Figure 4. The main microfacies types of the Asmari Formation in the studied wells: A) Anhydrite, B) Anhydrite bearing mudstone, C) Dolomudstone, D) Quartz-bearing wackestone, E) Echinoid wackestone, F) Benthic foraminifera wacke to packstone

Algal wackestone (MF10): The main constituents are *corallinacean* algae and some coral fragments within a micritic context. Minor skeletal grains including rotaliids, *Miogypsina*, echinoid, bivalve, and miliolid are observed (Fig. 5-D). The textural characteristics represent the middle ramp setting (Flügel, 2004) (Table 1).

Faverina packstone (MF11): The *Faverina asmarica* is the major constituent along with rare peloid and some benthic foraminifera (Fig. 5-E). Faverina is a type of fecal pellets generated by a marine crab and found in shallow marine carbonates of Mesozoic, sandy limestones of Jurassic and restricted lagoon deposits of Cretaceous (James & Wynd, 1965; Van Buchem et al., 2010). This facies represents the marginal marine setting of the basin (van Buchem et al., 2010) (Table 1).

Planktonic foraminifera wackestone to mudstone (MF12): *Globigerina* and minor fossils such as ostracod and *Ditrupa* are the main components (Fig. 5-F). Fine grains quarts and pyrite are also present in the micritic matrix. Based on the fauna and textural characteristics, this facies is attributed to deeper parts of the basin (outer ramp/ basin) (Flügel, 2004) (Table 1).

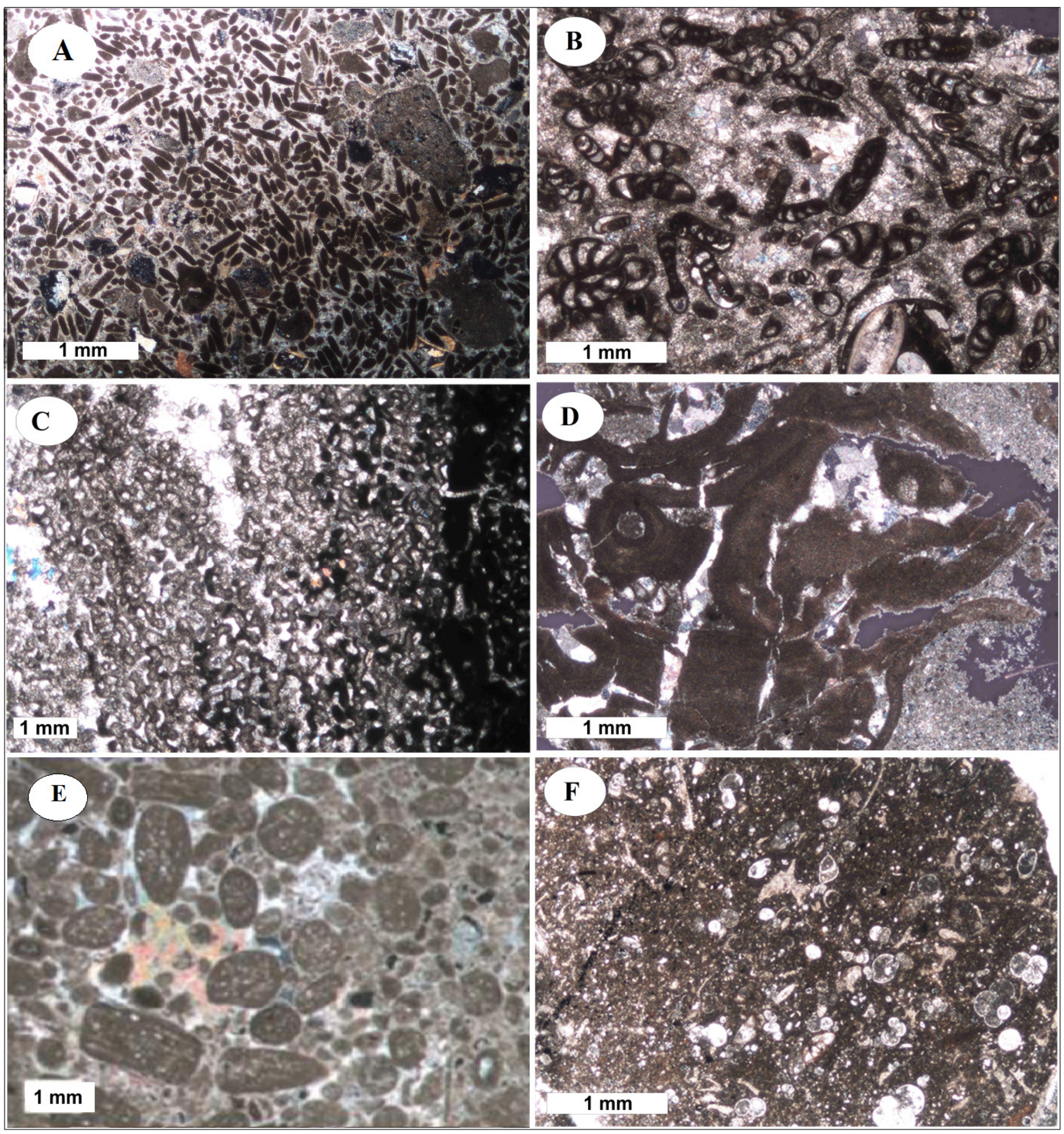

Figure 5. Continued the main microfacies types of the Asmari Formation in the studied wells: A) Peloidal wacke to packstone, B) Benthic foraminifera pack to grainstone, C) Coral boundstone, D) Algal wackestone, E) Faverina packstone, F) planktonic foraminifera wacke-mudstone

Diagenesis

To understand the reservoir quality of the Asmari Formation and its evolution during the post-depositional period, the diagenetic history of the Formation is depicted next to the facies analysis. The main detected diagenetic overprints are calcite and anhydrite cementation, physical and chemical compaction, dolomitization, dissolution, and fracturing which are related to marine, meteoric and burial diagenetic realms.

Diagenetic processes

Calcite cementation

This is one of the mostly recorded diagenetic overprints in the limy parts of the studied Formation. Various phases of calcite cementation are detected within the Asmari succession. Moreover, there are several traces of these cements in dolomitic parts of the section which mainly indicate pre-dolomitization calcite cementation (meteoric and burial).

The identified calcite cementation phases can be grouped into three main categories as marine, meteoric and burial, which are differentiable from each other by using their fabrics and morphologies.

Isopachous marine calcite cemention

Among different types of marine cements (e.g. Moore, 2001), the only detectable type in the studied samples is isopachous (Fig. 7A). The isopachous calcite cementation is rare and observed in grain-supported facies (MF8) which developed around ooids and other allochems. However, in the dolomitized grain-dominated facies there are some traces of this cement which due to the dolomitization are faded.

This process is the result of chemical precipitation of CaCO3 via seawater pumping into the grain-dominated facies in normal marine condition (Moore, 2001). Therefore, the distribution of marine cementation is generally controlled by wave energy, rates of sedimentation and initial sediment porosity. The intensity of early marine cementation decreases from shoal setting toward the land and offshore (Fig. 6). This type of cemention helps to porosity preservation in burial and late diagensis.

Syntaxial calcite overgrowth

This is visible as a rim of calcite crystals have grown by the extension of the lattice in allochems such as echinoids (Fig. 7B). These rims are mostly observed in echinoid wackestone microfacies and mainly concentrated in the upper part of the studied section (Fig. 3).

This cement type is not diagnostic of a particular diagenetic realm (Adams & MacKenzie, 1998) and reported from different diagenetic realms such as marine and meteoric phreatic to burial (e.g. Moore, 2001).

Drusy and equant calcite cementations

These calcite cementations are mainly recognized as intergranular and pore-fillings (Fig. 7C). Also, there is a close relationship between them. They are reported from both grain- and mud-dominated facies. The grain-dominated facies are composed of both intergranular and pore-filling types, but the mud-dominated facies are included of pore-filling (intra-fossil or chamber filling) type. These cements are distributed through the Asmari Formation (Fig. 3).

These cements are defined as a product of dissolution and cementation in phreatic-meteoric to burial realms (Moore, 2001; Scholle & Ulmer-Scholle, 2003).

Blocky calcite cementation

The coarse crystalline calcite cementation with sharp cleavages is defined as blocky calcite cement (Fig. 7D). This pore and fracture filling calcite cement is recognized through all parts of the Asmari Formation (Fig. 3). Blocky calcite cement is a product of burial diagenesis realm (Moore, 2001; Scholle & Ulmer-Scholle, 2003).

Neomorphism

The neomorphic calcite cement or pseudo-spar is visible in several parts of the studied formation of the Field. However, it is more evident in mud-dominated facies and includes recrystallized micritic matrix (Fig. 7D). Moreover, the fine crystalline and micritic allochems (such as peloids and ooids) of the limy intervals show neomorphic cement and recrystallization (Fig. 7A).

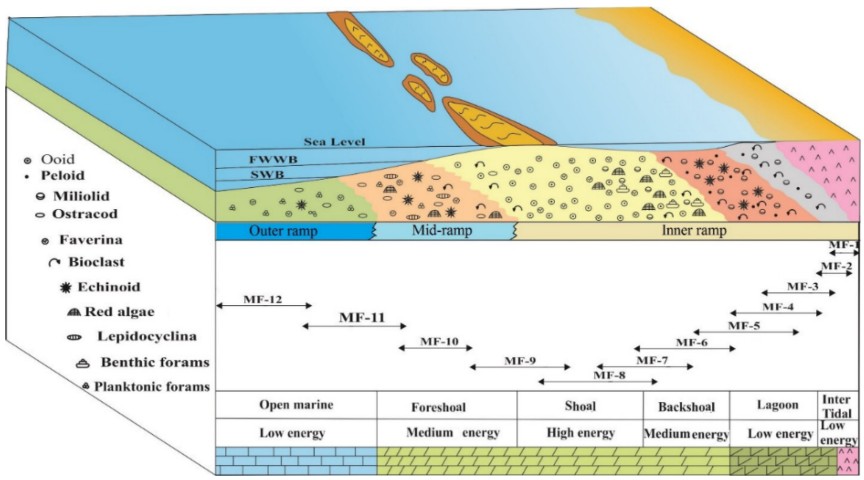

Figure 6. Schematic depositional model of carbonate ramp showing the distribution of microfacies associations and the related depositional environments of the Asmari Formation in the studied oil-field, SW Iran

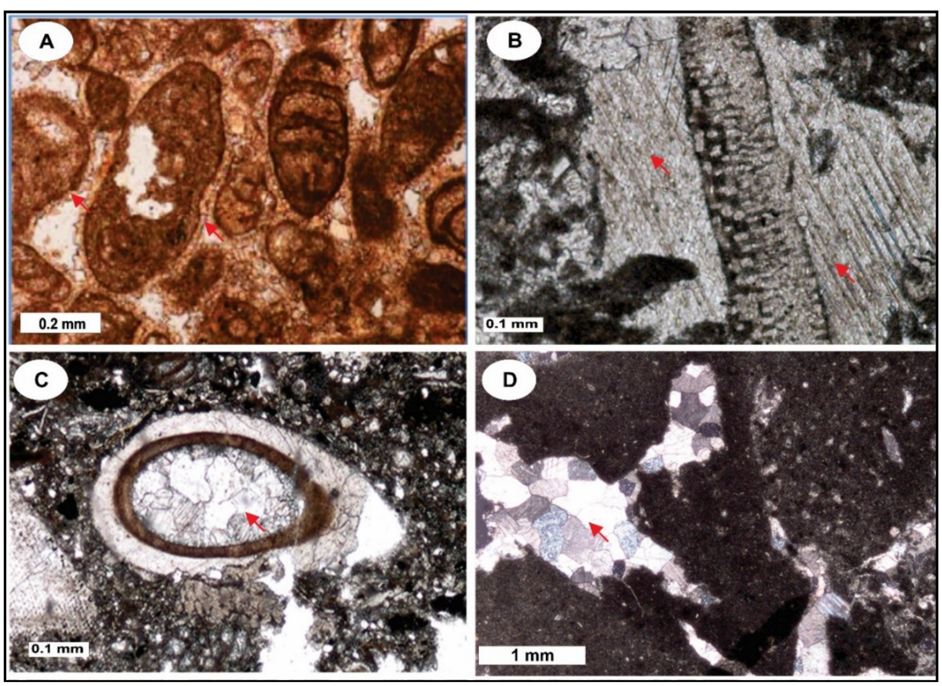

Figure 7. Different types of calcite cements. (A) Isopachous acicular cement around allochems, PPL., (B) Syntaxial cement around echinoid, PPL., (C) Drusy cement, PPL., (D) Blocky cement, XP

These cement type is interpreted as meteoric or deep burial diagenetic phase (Folk, 1965; Al-Aasm & Veizer, 1986) or only a burial phase (Tucker & Wright, 1990).

Anhydrite cementation

Anhydrite is a minor (diagenetic) phase in the studied cored interval of the Asmari Formation (Fig. 3). This mineralogy is mainly related to dolomitic parts of the Formation. However, because of its negative effect on the reservoir quality it is among the most important diagenetic imprints recorded within the studied succession.

It must be noted that there is rare features of the primary anhydrite precipitation (syn-depositional) in the studied successions and most of the detected anhydritic parts are post-depositional.

In general, two types of anhydrite cements are recognized in the Asmari Formation of the studied Field including (Figs. 8A and B): 1- Replacive and pore-filling, and 2- Fracture filling.

The replacive and pore-filling anhydrite cementations are visited as fillings of bioclasts' chambers, molds and vugs and replacements in both grain- and mud- dominated facies (Figs. 3 and 8A).

The fracture filling type of anhydrite cement is reported from some parts of the studied intervals (Fig. 3).

Seemingly, these phases and types of anhydrite cementation are related to hypersaline fluids and also remobilization of previously precipitated anhydrite (both depositional and diagenetic; Husain and Krouse, 1978).

Dissolution

The dissolution related features such as molds and vugs (Fig. 8C) are prominent in the studied Asmari interval of the Field and sometimes are plugged by later cementation (Fig. 3).

Deposition of the Asmari Formations in shallow parts of a ramp (Fig. 6), made them very sensible to sea-level fluctuations. During several relative sea-level falls (Fig. 2), various parts of the studied platform were emerged and altered by meteoric waters (e.g. van Buchem et al., 2010). During these times, the deposited carbonates and also grains with high solubility mineralogies (e.g. gastropod, bivalve, and benthic foraminifera) are dissolved (Moore, 2001 & Tucker, 2001)

Compaction

Physical or mechanical compaction caused reorientation or deformation of bioclasts especially in mud-supported microfacies and intervals of the studied Asmari Formation (Fig. 8D). These features are mainly reported from the upper part of the studied interval (Fig. 3). Features of chemical compaction including solution seams and stylolites as one the most visible diagenetic features in the Asmari Formation (Fig. 8E and 8F) are visible within both grain and matrix-dominated microfacies (Fig. 3).

Physical or mechanical compaction starts immediately after deposition and is driven by the effective stress applied on the sediments. However, overpressure reduces or stops mechanical compaction (Tucker, 1994). However, this process needs tens of hundred meters of burial (Bathurst, 1987).

Dolomitization

Dolomitization is one of the most important diagenetic alterations in the Oligocene-Miocene successions of Zagros, both in view of frequency and controls on reservoir properties (e.g. Aqrawi et al., 2006). Based on the petrographic analysis of available samples, several types of dolomites or dolomitization phases are recognized including fabric-retentive, fabric destructive and saddle (Fig. 9).

Fabric retentive dolomitization

This dolomitization phase is recognized as small crystals (>16 µm) which finely replaced all parts of the precursor limy facies (both allochems and micritic matrix; Figs. 9A and 9B). This phase is reported from all parts of the studied section of the Asmari Formation (Fig. 3).

Fabric destructive dolomitization

The fabric destructive dolomitization is destroyed allochems and sedimentary texture via replacement by dolomite rhombs (62-100 µm; Figs. 9C to 9F). It led to crystalline texture of the studied samples which differs from partial to wholly replacement (Figs. 9E and 9F) which usually postdated most of the recognized diagenetic features such as calcite cementation and followed by later anhydrite cementation. This type of dolomitization is visible in the uppermost, lowermost and middle part of the Asmari Formation (Fig. 3).

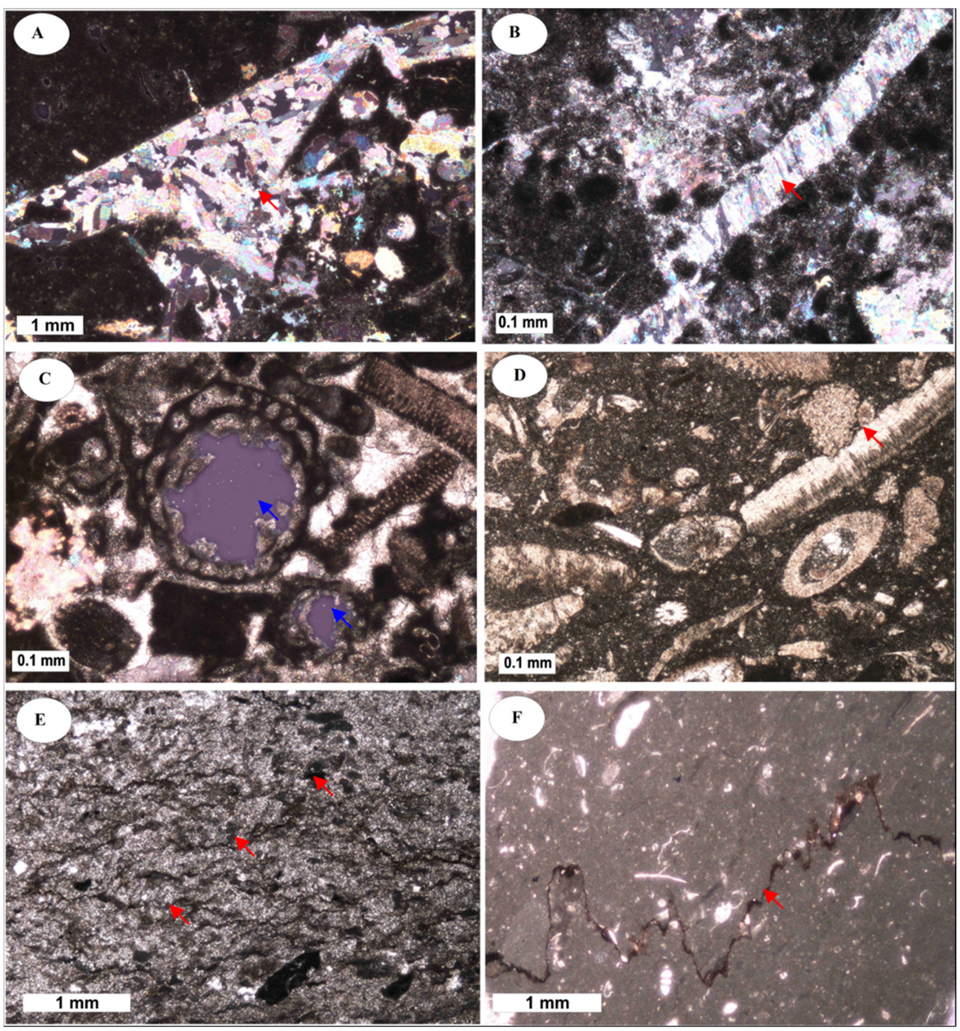

Figure 8. Continued (A) Pore-filling anhydrite, XPL., (B) Fracture-filling anhydrite cement, XPL., (C) Dissolution, which resulted in producing moldic porosity, XPL., (D) Mechanical/ Physical compaction in Mud-dominated microfacies, XPL., (E) Solution seam, PPL. (F) Stylolite, PPL

Following downward percolation of hypersaline fluids thorough the formerly deposited carbonate sediments (seepage-reflux model; Saller & Henderson, 1998; Melim & Scholle, 2002) there is a spectrum of dolomitization intensity from fabric retentive to fabric destructive types with decreasing Mg/Ca ratio (Figure 7-14).

Saddle dolomite

Saddle dolomite is recognized as replacive and fracture-filling coarse crystals (>100 µm) with typical curved cleavages and undulose extinction (Figs. 9G and 9H). The saddle dolomites are recognized in the upper and lowermost parts of the Asmari Formation (Fig. 3).

Saddle dolomites show burial realm and oil-window with temperatures of 100 to 150 ºC (Esteban & Taberner, 2003; Machel, 2005).

Fracturing

Fractures in the studied Asmari Formation are classified into open and filled. They are filled by calcite, anhydrite and saddle dolomite (Figs. 4A, 5D, 8B and 9H). Open fractures are visible in the upper part of the studied section (Fig. 3). Fractures are recorded in both limestones and dolostones and all microfacies.

Some evidence such as their development in dolomitic intervals (Fig. 8B) and blocky calcite and saddle dolomite fillings confirms their development during the burial.

Diagenetic realms and paragenesis

Based on the detected diagenetic features during the petrographic analysis of the Asmari Formation, four diagenetic realms were differentiated as follows:

Marine diagenesis

Just after deposition in marine sedimentary environments, carbonate sequences were undergone diagenetic modifications. Marine cementation is typical of high energy shoal? facies in form of isopachous cements surrounded allochems. In such high energy environment, continuous charging of sea water into the pore spaces of sediments (high water to rock ratio) caused chemical precipitation of CaCO3 as isopachous cements. Intense marine cementation of carbonate sediments can provide a rigid framework against the subsequent diagenetic modifications, especially mechanical and chemical compaction. However, due to low frequency of typical shoal facies and later diagenetic overprints in the studied successions, it is not frequent.

Meteoric diagenesis

The presence of filled molds (Fig. 8A) and vuggy pores through the Asmari interval and also some calcite cement types such as drusy and equant calcite cements, indicate effects of meteoric diagenesis realm. Rather than meteoric dissolution and consequent cementation, mineral stabilization and replacement by equant and drusy and later blocky (burial) calcite cements is other alteration of this stage (Figs. 7C and 7D). The dissolution of meta- to unstable (aragonitic) grains, commonly bivalves and (small) benthic foraminifera (Fig. 8C), has resulted in fabric selective pore spaces (moldic and, to some extent, vuggy) in the studied formation. Therefore, this process must be considered as early diagenetic features that have affected carbonate sequences before their consolidation in burial realms.

Hypersaline/shallow burial diagenesis

Hypersaline diagenesis is one of the most important and effective diagenetic stages, which have had considerable impacts on the history of reservoir evolution of the Asmari carbonates and also other dolomitic reservoirs (e.g. Aqrawi et al., 2006).

In dolomitic parts of the studied intervals, dolomitization phases occurred as fabric retentive and fabric destructive. In general, after precipitation of evaporites in the nearby supratidal setting or evaporation in the restricted parts of the lagoon, remaining fluids are supersaturated relative to Mg and Ca, and then percolated through formerly deposited limy and mud- to grain dominated sediments– with interparticle porosity and flow potential–in both basin- and downward directions.

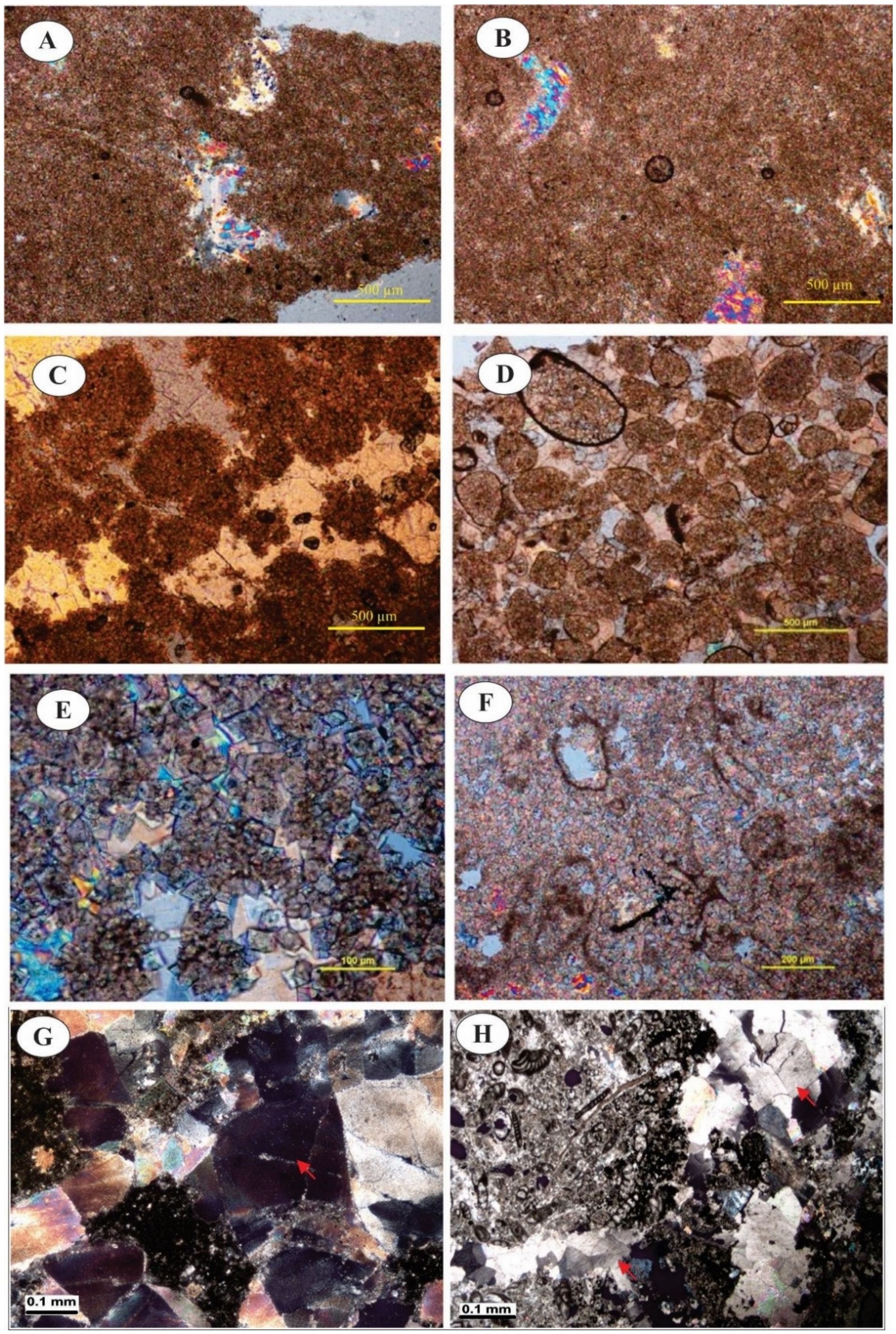

Figure 9. Different types of dolomite in the Asmari Formation. A, B) dolomicrite, C, D) fabric-retentive, E, F) fabric-destructive, G, H) Saddle form dolomite

This phenomenon has occurred just after deposition of carbonate mud in intertidal and subtidal settings (Chafetz et al., 1999; Warren, 2000; Meyer, 2005).

Following downward percolation of hypersaline fluids thorough the formerly deposited carbonate sediments (seepage-reflux model; Saller & Henderson, 1998; Melim & Scholle, 2002) there is a spectrum of dolomitization intensity from fabric retentive to fabric destructive types with decreasing Mg/Ca ratio. Moreover, pore-filling and replacive anhydrite cementation has a close relationship with these hypersaline related dolomites which led to plugging of pores (Saller & Henderson, 1998).

Burial diagenesis

After experiencing marine, meteoric and hypersaline, the studied Oligocene-Miocene succession has undergone shallow to deep burial diagenesis. Under high temperature - pressure condition of burial realm, several diagenetic alterations have affected the studied interval.

Several diagenetic processes are detected as follows: syntaxial calcite overgrowth, blocky calcite cementation, compaction, neomorphism, saddle dolomite and fracturing. The latest phase of dolomitization in the Asmari Formations is saddle dolomite which has a correlation by the minimum required depth of 500 m and temperature of > 30 ºC for chemical compaction (Machel, 1999; Duggan et al., 2001).

The occurrence order (relative timing) of diagenetic processes was acquired by studying of their textural relationships in petrographic studies. The paragenesis of detected diagenetic features is presented in Fig. 10 for the targeted intervals of the Field. In these successions, all diagenetic processes are arranged based on their occurrence time relative to their subsequent alterations. Among these phases, only some processes such as dissolution, dolomitization, and later fracturing had potential to create reservoir quality.

Sequence Stratigraphy

A comprehensive Asmari succession sequence stratigraphy has been investigated in both outcrop and well in different places in SW Iran. For example, van Buchem et al., (2010) based on isotope data, have distinguished three 3rd order sequences of Oligocene (Rupelian, early Chattian and late Chattian in age) and three Miocene sequences (early Aquitanian, late Aquitanian and early Burdigalian in age), at Tang-e-Gurgudan outcrop section, in the Dezful and Izeh Zones. Also, three Miocene sequences identified in one well (Well #13) by van Buchem *et al.,* (2010) in the Dezful depression (Fig 10).

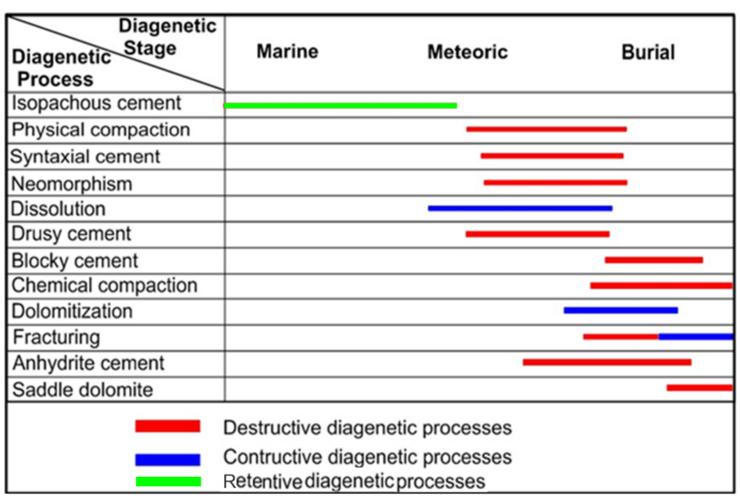

Figure 10. Diagenetic history of the Asmari Formation and impact of diagenesis on reservoir quality

To construct a sequence stratigraphic framework and determine the key surfaces, different data containing the results of facies studies, logs response and the appearance or abundance of fossils (e.g. the ratio of planktonic to benthic foraminifera) are used.

The sequence boundaries were characterized by remarkable facies changes in the depositional succession and special diagenetic imprints associated with sea-level falling stage.

Accordingly, three 3rd-order Miocene sequences are identified (Fig. 10): Sequences 4 and 5, related to Aquitanian (Early Miocene), both begun with low-stand sedimentary packages of subaqueous anhydrides (known as 'Basal and Middle Anhydrite') that were precipitated from the basin center when the basin became isolated from the Neo-Tethys Ocean, meanwhile, sequence 6 is related to the Late Miocene (Burdigalian).

Since Oligocene Asmari deposits (lower Asmari) did not develop in the studied field, the three Oligocene sequences introduced by van Buchem et al., (2010) have not been distinguished. Generally, the Middle Asmari includes two sequences, namely sequences 4 and 5. The Upper Asmari comprises one sequence (sequence 6), (Fig. 10). During highstand systems tracts, the Middle and Upper Asmari successions were in a closed sedimentary basin with high salinities, supplying appropriate conditions for dolomitization (Aqrawi & Wennberg, 2007). This can also observed by the existence of both anhydrite nodules and cements within dolomitized beds.

Discussion

Depositional setting of the Asmari Fm.

According to detailed petrographic analysis, 12 recognized microfacies (Table 1) are classified into five facies belts including tidal flat (MF1, MF2, MF3), lagoon (MF4, MF5, MF6 and MF7), barrier (inner ramp, MF8, MF9), middle ramp (MF10) and outer ramp (MF11, MF12) (Fig. 11; Table 1). The outer ramp is determined by marly limestone and planktonic foraminifera wackestone specially *Globigerina* spp. and *Detropa*

The dominance of the mud-support microfacies and the absence of sedimentary structures formed in the presence of wave currents indicate that MF12 was formed in an outer ramp setting (under storm wave base, SWB). The middle ramp is mainly characterized by algal wackestone, but some boundstone facies including coralline boundstone and bioclastic grainstone belonging to the sea-ward shoal can be attributed to the middle ramp setting. The inner ramp deposit includes high energy grainstone barrier, open marine and restricted lagoon, intertidal and supratidal facies. The restricted lagoon was characterized by the absence of marine fauna and low frequency of common bioclasts and also lack of porcelaneous benthic foraminifera (Miliolids, Borealis), which indicate limited water recirculation and restricted environment condition. According to gradual facies transitions and lack of evidence of turbidite deposits, slump structures and debris, significant reef structures, pisoids, and oncoids, it is indicated that the Asmari Formation was deposited on a homoclinal ramp-type carbonate platform in the studied field (Burchette & Wright, 1992) from the Aquitanian to Burdigalian (i.e. Early Miocene).

Distribution of facies and their effects on reservoir quality

Interpretation of the result of facies analysis and their distribution in the studied wells indicated that moderate to good reservoir the high energy shoal facies (Table 2; MF9) have less abundance in the studied wells (Fig. 10, i.e. depth: 1620-1625 Well A; 1410-1430 Well C; 1845-1850 Well D). In the backward shoal, shallow and mostly low-energy lagoon setting has established, in which various benthic organisms have developed with low biodiversity (Wilson, 1975; Buxton & Pedley, 1989; Flügel, 2004). These types of facies constitute a major part of the Asmari Formation in the studied field (Fig. 10, most extension is related to lagoonal facies with bad reservoir quality i.e. MF4, 5) (Table 2), in which their reservoir quality is enhanced through moldic and vuggy dissolution and intragranular porosities (Fig. 7-C and D) (Table 2).

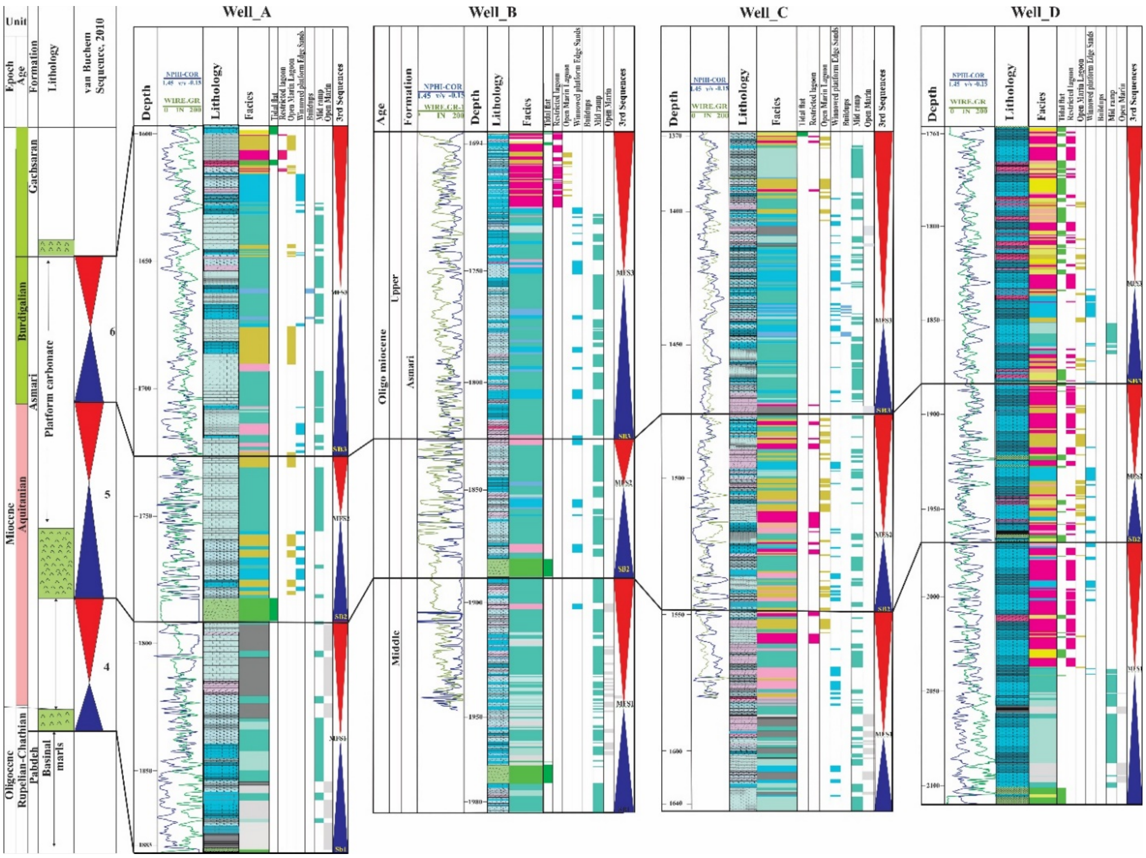

Figure 11. Sequence stratigraphic correlation between the studied wells and Well-13 (from van Buchem et al., 2010). The key sequence surfaces (maximum flooding surfaces and sequence boundaries) determined are based on microfacies properties, gamma-ray log data and paleontological evidence (ratio of planktonic to benthic foraminifera)

Table 2. Main petrophysical property of the recognized microfacie for the Asmari succession in the studied oil field

Microfacies	Depositional Environment	Porosity (Fraction)			Permeability (mD)		
		Min	Max.	Ave.	Min.	Max.	Ave
MF1	Supratidal	0.002	0.100	0.010	0.020	0.800	0.070
MF2	Supratidal to intertidal	0.020	0.150	0.100	0.010	1	0.090
MF3	Intertidal	0.080	0.290	0.200	0.120	20	15
MF4	Lagoon	0.012	0.250	0.08	0.010	15	0.04
MF5	Lagoon	0.025	0.120	0.085	0.100	0.800	0.400
MF6	Restricted lagoon	0.010	0.280	0.120	0.010	9	0.200
MF7	Lagoon	0.120	0.220	0.190	0.150	16	2
MF8	Back shoal	0.015	0.200	0.100	0.010	3	0.250
MF9	Shoal (inner ramp)	0.020	0.200	0.080	0.010	10	0.200
MF10	Middle ramp	0.017	0.100	0.003	0.100	0.500	0.300
MF11	Open marine	0.060	0.120	0.075	0.070	1	0.300
MF12	Outer ramp/ basin	0.010	0.180	0.120	0.010	100	0.1

Their poro-perm data suggest their diagenesis was possibly facies-dependent. An increase in energy of the carbonate platform, which leads to the cleanliness of the matrix and the formation of grain-dominated facies (MF7, MF8, and MF9) (Figs. 3 and 10 and Table 2), is among the factors contributing to the formation of better reservoir facies (Fig 12: MF6 and Fig. 13: MF7, MF8) (Table 2). However, these facies are less found in the studied interval of Asmari Formation or limited to specific units (Figs. 3 and 10). The results obtained from facies analysis indicate that the middle part of the Asmari Formation is mainly consists of outer and middle ramp facies (sequence 4 and 5), whereas the upper Asmari Formation (sequence 6) is deposited on a relatively high-energy platform (the presence of the middle/inner ramp facies), and shows shoaling-upward cycles towards the evaporitic Gachsaran Formation (Fig. 10).

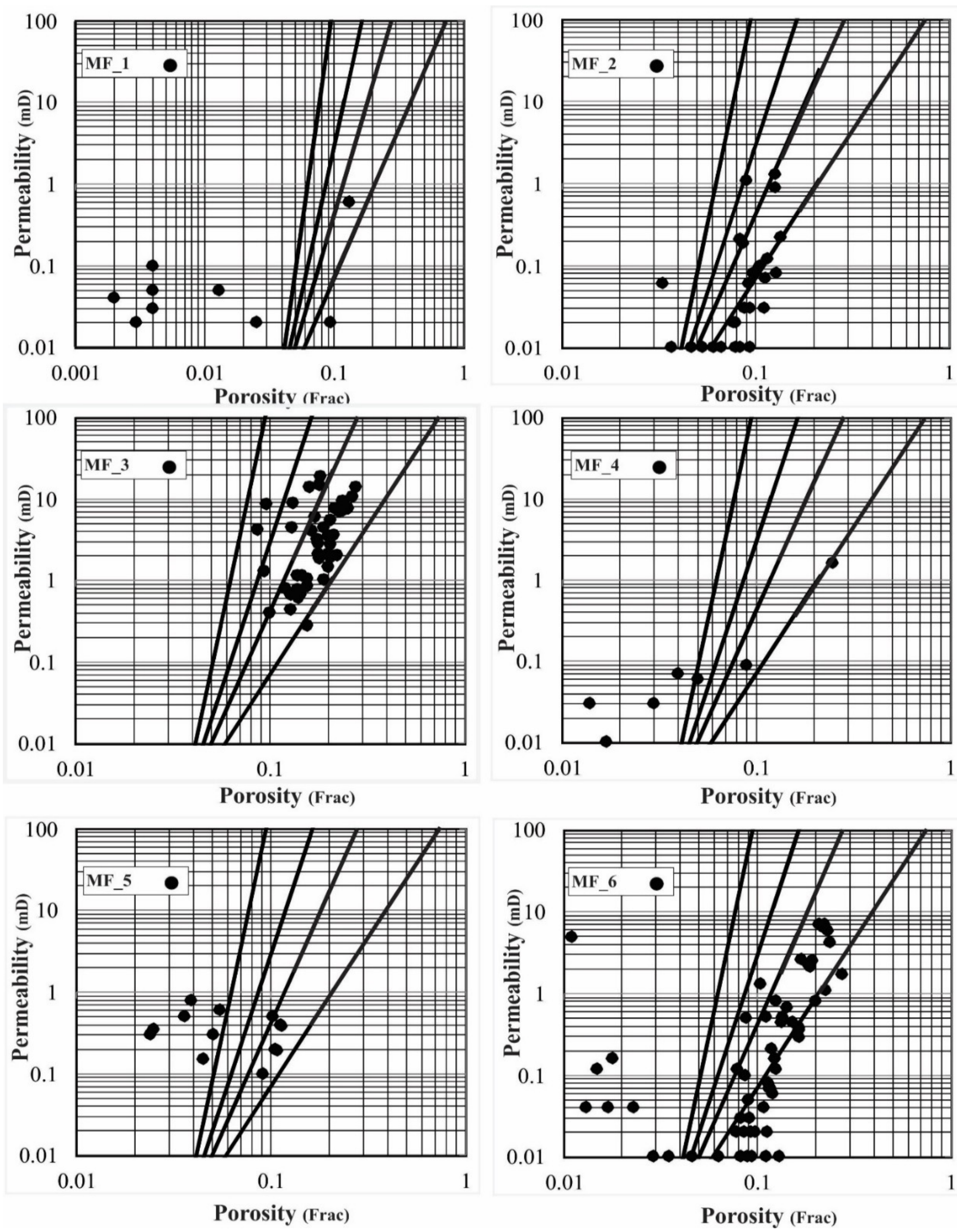

Figure 12. Porosity versus permeability on the Lucia rock fabric class (Lucia, 2007) for the MF1 to MF6

Eventually, it is concluded that MF3 (intertidal), MF 6 and 7 (lagoon), MF 8 (back shoal), MF9 (shoal) and MF12 (basin) have good reservoir quality (Table 2, Figs. 12 and 13). There reservoir quality are originated from the depositional characteristics of the facies. In other words, the main controlling factor on their reservoir quality was depositional characteristics and/or a facies-dependent diagenesis.

Linking diagenesis to the facies types and their controls on reservoir quality

Diagenetic processes including cementation, dissolution and dolomitization as well as features have resulted in different reservoir quality of the same facies in the studied wells (Fig. 14 well B and C; Fig. 15).

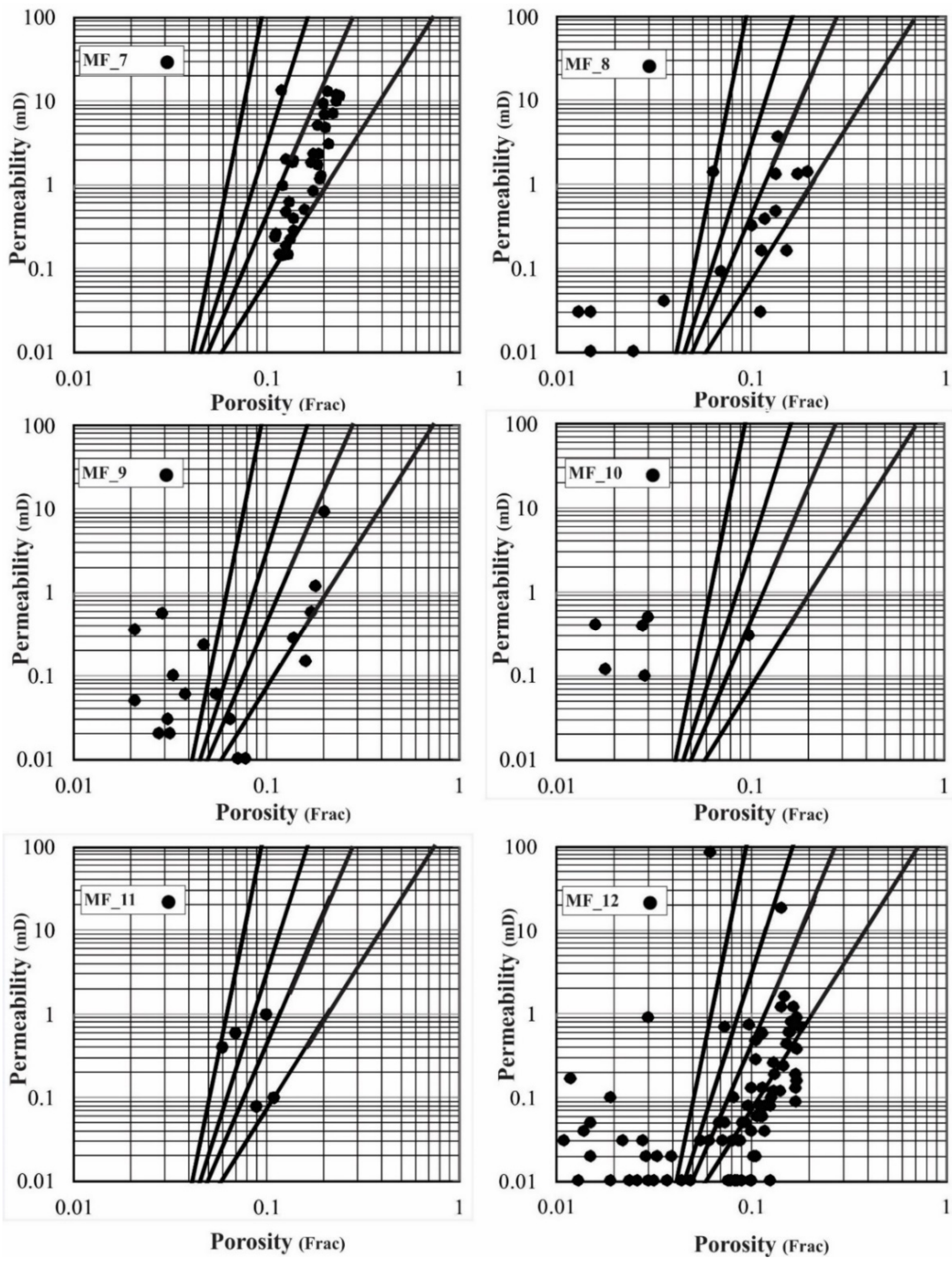

Figure 13. Porosity versus permeability on the Lucia rock fabric class Lucia, (2007) for the identified MF7 to MF12

Dolomitization and other digenesis processes, i.e., dissolution and fracturing have affected the Asmari Formation, that led to the generation of porosity and permeability and development of reservoir characters system (Fig. 14 and Figs. 15-B, C and D), especially in Lagoon microfacies which have been dolomitized (Fig. 7-C and Fig. 8) (Table 2).

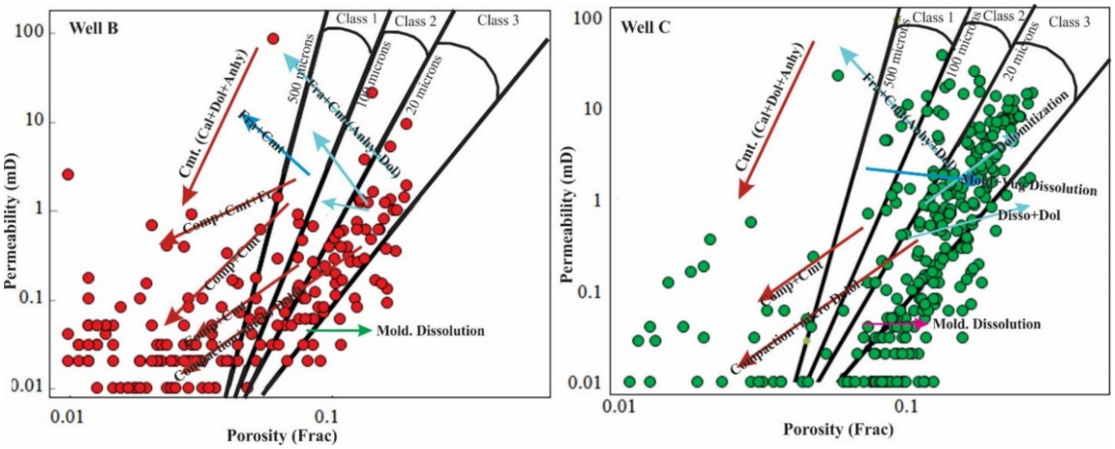

Figure 14. Illustrate the effect of diagenetic processes on porosity and permeability of the Asmari reservoir in the studied field.

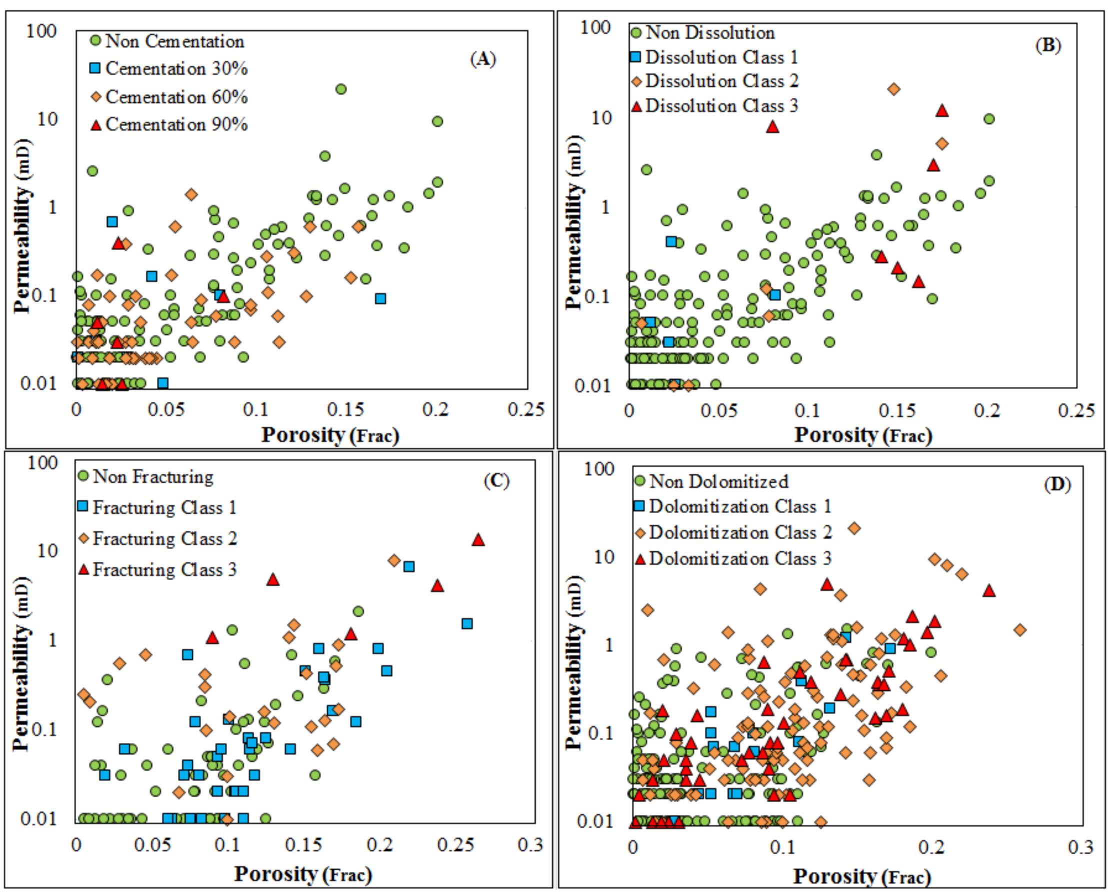

Figure 15. Impact of diagenetic processes on reservoir quality. A) With increasing in cementation process, reservoir quality is decreased, B) Increasing in dissolution value from class 1 to 3 resulted in the enhancement of reservoir quality, C) Fracturing improved reservoir quality of the Asmari Formation and E) Increasing in dolomitization level resulted in reservoir quality development

However, permeability at the uppermost interval of the Upper Asmari is decreased due to fracture filling anhydrite cement (Fig. 3, Fig. 7-A, B and Fig. 15-A). Compaction and cementation (Anhydrite and Calcite) have had negative effects on reservoir quality (Fig. 14, Fig. 15-A and Fig. 6-D, E). Anhydrite and calcite cements mostly filled both pore spaces and fractures and therefore have decreased reservoir quality (Fig. 14 and Fig. 15-A).

Dolomitization through evaporate brines (Fig. 9) is another cause for improving porosity and permeability in mud-dominated intertidal to lagoonal facies (MF3, MF5 and MF6; Table 2) (Figs. 12, Fig. 13 and Fig. 15-D). However, the permeability values are generally less than 10 MD due to the fine-sized crystals of dolomites (Fig. 8-A, B) or the fracture-filling anhydrite cements (Fig. 7-A, B and Figs. 12 and 13). Next to the fracturing, dolomitization processes had main constructive effect on the reservoir quality of the studied reservoir (Fig. 14 and Fig. 15-D). Dissolution, as one of the major causes of porosity enhancement (especially in the upper part of HST), is mainly developed in benthic foraminifera wacke/pack to grainstone facies (MF6 and MF8) (Fig. 3 and Fig. 7-C), which have less abundance in the studied field (Fig. 14 and Fig. 15-B). The high porosity values of MF6 and MF7 are mainly resulted from the development of vuggy porosities and intercrystalline porosity (Figs. 12, 13 and Fig. 15-B). Compaction features (both mechanical and stylolite forms) have negative impact in mud-dominated facies (i.e, MF6 and MF11) (Fig. 7-D, E and Fig. 14). Therefore, two major factors of primary depositional environment (mineralogical composition and initial texture) and development of vuggy and intercrystalline porosities (Fig. 15-B) along with fracturing (Fig. 15-C) and dolomitization (Fig. 15-D) processes have made reservoir potential.

Linking reservoir quality to the sequence stratigraphy

Interpretation of the results of sequence stratigraphy and its comparison with the facies distribution as well as reservoir quality indicates a relatively direct relationship between reservoir parameters and identified system tracts. Overall, TST, is composed of lagoonal (restricted/ open marine lagoon) facies (MF1, MF4, MF5, MF6 and MF7), whereas, HST consists of bioclastic grainstone (MF8) and coral boundstone facies (MF9) of the inner ramp. Due to the presence of benthic foraminifera pack to grainstone and coral boundstone as well as inter/intra-particle porosities from dolomitization and dissolution of the unstable aragonite components (e.g., *Borelis* fossil, Fig. 6-C) in these facies in the HST, on the one hand, and the dominance of mud-supported facies with limy micrite and calcite/ anhydrite cements in the TST, on the other hand, reservoir quality of the HST is higher than the TST (Figs. 16 and 17) (Table 3). From maximum flooding surface towards the sequence boundary (Fig. 17), reservoir quality has been improved through the creation of vuggy porosities (resulted from meteoric dissolution, Fig. 7-C) and intercrystalline porosities (resulted from dolomitization, Fig. 8-E). In contrast, the reservoir quality has been decreased towards the MFS because of the presence of mud-supported facies of the distal middle ramp and outer ramp (Fig. 17). The sequence 4 has the worst reservoir quality in the studied wells, particularly in well B, in which cementation (mostly anhydrite cement) resulted in decreasing porosity and permeability (Fig. 16 and Table 3).

Table 3. Main petrophysical property of the identified sequence and systems tract for the Asmari succession in the studied oil field

Sequence	Systems Tact	Porosity			Permeability		
		Min	Max.	Ave.	Min.	Max.	Ave
Seq. 6	HST	0.015	0.200	0.15	0.03	20	0.800
	TST	0.01	0.20	0.070	0.01	0.300	0.070
Seq. 5	HST	0.01	0.180	0.120	0.01	100	0.200
	TST	0.015	0.180	0.100	0.010	0.100	0.050
Seq. 4	HST	0.010	0.170	0.04	0.010	2.50	0.100
	TST	0.013	.080	0.03	0.010	0.400	0.030

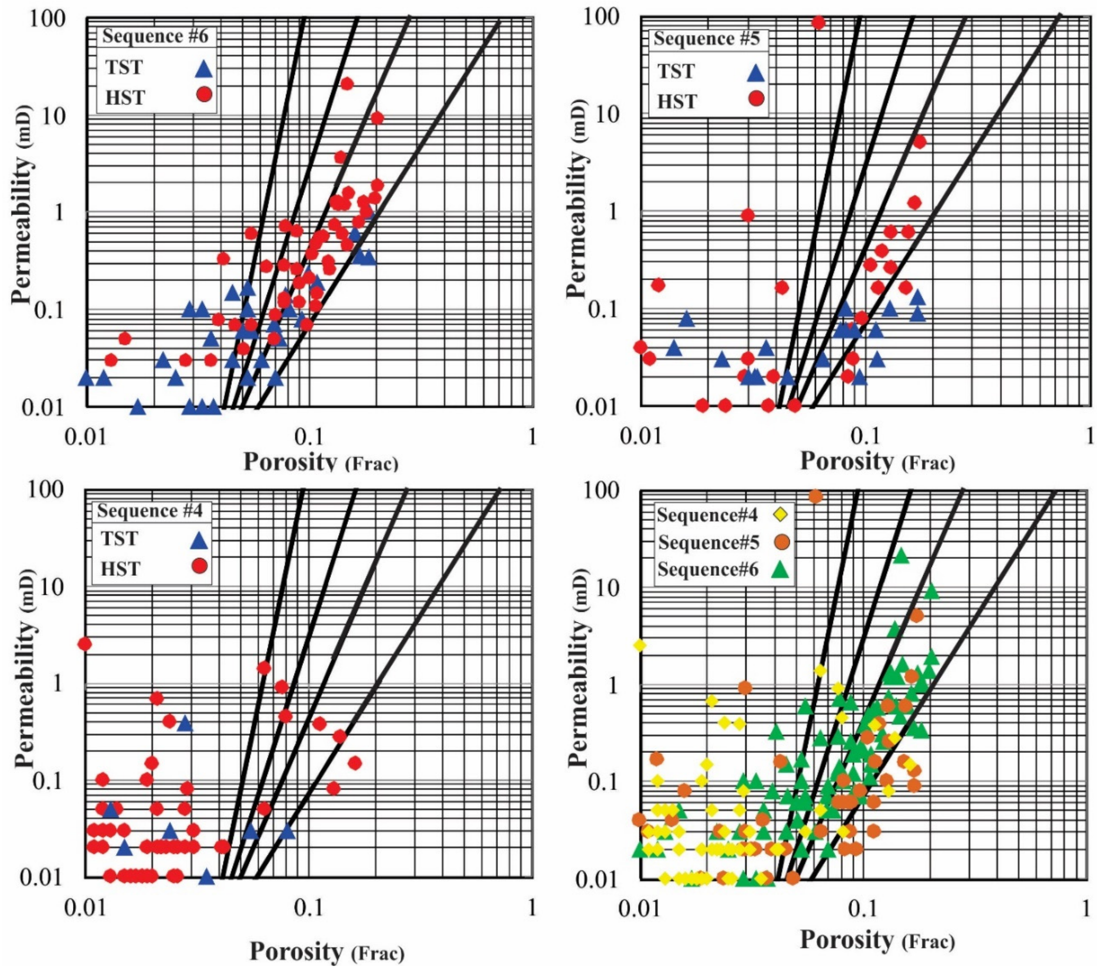

Figure 16. Porosity-permeability cross-plot of the introduced sequence and systems tract of the Asmari Formation representing high reservoir quality of HST than TST resulted from dolomitization, fracturing and dissolution

The upper sequence of Asmari (sequence 6) is composed of the wide-range facies (outer ramp to barrier facies in TST and lagoonal to supratidal facies in HST part) in the observed wells, which is indicative of a relatively constant eustacy at the Burdigalian stage. This sequence shows better reservoir quality than the middle Asmari (sequences 4 and 5) (Fig. 16), due to the high frequency of high quality reservoir facies (MF3, 6, 7 and 8) along with the influence of constructive diagenetic features such as dissolution and dolomitization (Fig. 3, Figs 15-B and D) (Table 3). Overall, reservoir quality from sequence 4 toward sequence 6 due to increases in dolomitization, more dissolution along with stability of the basin resulted in constant increases in sea level in Burdigalian (it is concluded from the high thickness of the sequence and more uniformity/similarity of the facies) is increased (Fig. 3, Fig. 15 and Fig. 16) (Table 3).

Conclusions

Based on petrographic observation, 12 microfacies belonging to a homoclinal ramp-type system have been identified. These facies were classified into five sub-environment including tidal flat, lagoon, barrier, middle ramp, and outer ramp. Tidal flat, lagoonal and barrier microfacies mostly present in the upper and some middle parts of the Asmari reservoir, while middle and outer ramp microfacies largely developed in the middle part.

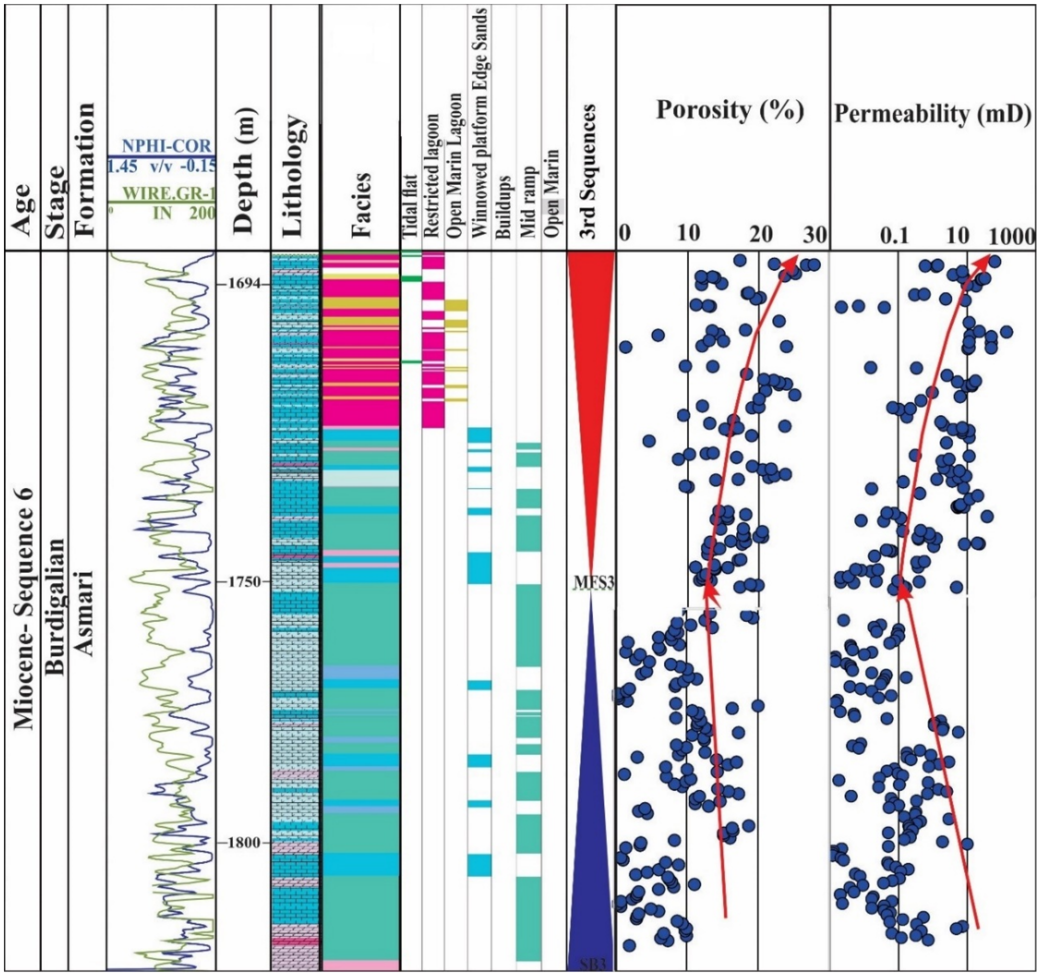

Figure 17. Reservoir quality distribution in the upper part of the Asmari Formation (Sequence 6); the values of the porosity and permeability increase towards the sequence boundary

Results of depositional environment study indicate that an inner and middle part of a homoclinal ramp dominated during the deposition of the Asmari succession in the studied field. Intertidal (MF3), lagoon (MF 6 and 7), back shoal (MF 8), and basin (MF12) have good reservoir quality, that indicated reservoir quality are originated from the depositional characteristics of the facies. In other words, the main controlling factor on their reservoir quality was depositional characteristics and/or a facies-dependent diagenesis.

The major diagenetic processes affecting the Asmari succession include compaction, cementation, dolomitization, dissolution, and fracturing. Whereas dissolution, dolomitization, and fracturing are contributed to porosity and permeability enhancement, cementation and compaction have reduced the reservoir quality. Intercrystalline pore spaces created from dolomitization (especially fabric retentive dolomitization in inner ramp facies), molds and vuggy pore space resulted from dissolution are the most important diagenetic pore type that has affected the reservoir quality.

From the sequence stratigraphic perspective, the Lower Asmari has not been recorded in the studied oil-field. Three 3rd-order Miocene sequences are distinguished on the basis of deepening and shallowing trends of facies. Sequence 6 has the best reservoir quality in the studied oil-field. Highstand systems tract in this sequence has better reservoir quality than transgressive system tract because of the dolomitization, fracturing, and dissolution.

Acknowledgements

The authors express their appreciation to the National Iranian South Oil Company (NISOC) for providing data. The financial support of the Azad University is also appreciated.

References

Adams, A. E., Mackenzie, W. S., 1998. A Colour Atlas of Carbonate Sediments and Rocks Under the Microscope. Manson Publishing Ltd, London.

Aghanabati, A., 2004. Geology of Iran. Geological survey of Iran, p.582.

Ahr, W.M., 2008. Geology of carbonate reservoirs. John Wiley and Sons, Chichester, p.296.

Al-Aasm, I. S., Veizer, J., 1986. Diagenetic stabilization of aragonite and low-Mg calcite; I, Trace elements in rudists. Journal of Sedimentary Research, 56 (1): 138-152.

Alavi, M., 2004. Regional stratigraphy of the Zagros fold-thrust belt of Iran and its pro foreland evolution. American journal of science. 304 (1): 1-20.

Alsharhan, A.S. and Kendall, C.G.S.C., 1986. Precambrian to Jurassic rocks of Arabian Gulf and adjacent areas: their facies, depositional setting, and hydrocarbon habitat. American Association of Petroleum Geologists Bulletin, 70(8): 977-1002.

Alsharhan, A.S. and Whittle, G.L., 1995. Carbonate-evaporite sequences of the Late Jurassic, southern and southwestern Arabian Gulf. American Association of Petroleum Geologists Bulletin, 79 (11): 1608-1630.

Aqrawi, A. 2007. The Control of fracturing and dolomitisation on 3D reservoir property distribution of the Asmari Formation (Oligocene-Lower Miocene), Dezful Embayment, SW Iran. International Petroleum Technology Conference held in Dubai, U.A.E., 4-6 December, 7 p.

Aqrawi, A.A.M., Keramati, M., Ehrenberg, S.N., Pickard, N., Moallemi, A., Svånå, T., Darke, G., Dickson, J.A.D., Oxtoby, N.H., 2006. The origin of dolomite in the Asmari formation (Oligocene-lower Miocene), Dezful embayment, SW Iran. Journal of Petroleum Geology, 29 (4): 381-402.

Avarjani, S., Mahboubi, A., Moussavi-Harami, R., Amiri-Bakhtiar, H., Brenner, R.L., 2015. Facies, depositional sequences, and biostratigraphy of the Oligo-Miocene Asmari Formation in Marun oilfield, North Dezful Embayment, Zagros Basin, SW Iran. Palaeoworld, 24 (3): 336-358.

Bathurst, R. G. 1987. Diagenetically enhanced bedding in argillaceous platform limestones: stratified cementation and selective compaction. Sedimentology, 34 (5): 749-778.

Berberian, M. and King, G.C.P., 1981. Towards a paleogeography and tectonic evolution of Iran. Canadian Journal of Earth Sciences, 18 (2): 210-265.

Burchette, T.P. and Wright, V.P., 1992. Carbonate ramp depositional systems. Sedimentary Geology, 79(1-4): 3-57.

Buxton, M.W.N., Pedley, M., 1989. Short paper: a standardized model for Tethyan Tertiary carbonate ramps. Journal of the Geological Society, 146: 746-748.

Chafetz, H.S., Imerito-Tetzlaff, A.A., Zhang, J.L., 1999. Stable isotope and elemental trends in Pleistocene sabkha dolomites: Descending meteoric water vs. sulfate reduction. Journal of Sedimentary Research, 69(1): 256-266.

Daraei, M., Bayet-Goll, A. and Ansari, M., 2017. An integrated reservoir zonation in sequence stratigraphic framework: A case from the Dezful Embayment, Zagros, Iran. Journal of Petroleum Science and Engineering, 154: 389-404.

Dickson, J.A.D., 1965. A modified staining technique for carbonates in thin section. Nature, 205(4971): 587.

Duggan, J.P., Mountjoy, E.W. and Stasiuk, L.D., 2001. Fault-controlled dolomitization at Swan Hills Simonette oilfield (Devonian), deep basin west-central Alberta, Canada. Sedimentology, 48: 301-323.

Dunham, R. J., 1962. Classification of carbonate rocks according to depositional texture. In: Ham, W.E., ed., Classification of Carbonate rocks: American Association of Petroleum Geologists Special Publications, 1: 108-121.

Ehrenberg, S. N., N. A. H. Pickard, G. V. Laursen, S. Monibi, Z. K. Mossadegh, T. A.Sva˜na, A. A. M. Aqrawi, J. M. McArthur, M. F. Thirlwall, 2007. Strontium isotope stratigraphy of the Asmari

Formation (Oligocene- Lower Miocene), SW Iran, Journal of petroleum geology, 30: 107-128.
Esteban, M., Taberner, C., 2003. Secondary porosity development during late burial in carbonate reservoirs as a result of mixing and/or cooling of brines. Journal of Geochemical Exploration, 78-79: 355-359.
Farshi, M., Moussavi-Harami, R., Mahboubi, A., Khanehbad, M. and Golafshani, T., 2019. Reservoir rock typing using integrating geological and petrophysical properties for the Asmari Formation in the Gachsaran oil field, Zagros basin. Journal of Petroleum Science and Engineering, 176: 161-171.
Flügel, E., 2004. Microfacies of carbonate rocks. Springer-Verlag, Berlin, Pp.976.
Folk, R.L., 1965. Some aspects of recrystallization in ancient limestones. In: Pray LC, Murray RC (eds) Dolomitization and limestone diagenesis. American Association of Petroleum Geologists Special Publication, 13: 14-48.
Hollis, C., Sharp, I., 2011. Albiane Cenomaniane Turonian carbonate-siliciclastic systems of the Arabian Plate: advances in diagenesis, structure and reservoir modelling: introduction. Petroleum Geoscience, 17: 223-241.
Husain, S. A., & Krouse, H. R. 1978. Sulphur isotope effects during the reaction of sulphate with hydrogen sulphide. In Stable isotopes in the earth sciences.
James, G. A., J. G. Wynd, 1965. Stratigraphic nomenclature of Iranian oil consortium agreement area, American Association of Petroleum Geologists Bulletin, 49: 2182-2245.
Longman, M. W., 1980. Carbonates diagensis tetures from near surface diagenetic environment, Association of Petroleum Geologists Bulletin, 64(4): 461-487.
Lucia, F.J., 2007. Carbonate Reservoir Characterization. Springer-Verlag, Berlin, p.341.
Machel, H.G., 1999. Effects of groundwater flow on mineral diagenesis, with emphasis on carbonate aquifers: Hydrogeology Journal, 7: 94-107.
Machel, H.G., 2005. Investigations of burial diagenesis in carbonate hydrocarbon reservoir rocks. Geoscience Canada.
Melim, L. A., & Scholle, P. A. 2002. Dolomitization of the Capitan Formation forereef facies (Permian, west Texas and New Mexico): seepage reflux revisited. Sedimentology, 49(6): 1207-1227.
Meyer, F.O., 2005. Anhydrite classification according to structure. Available from: http://www.crienterprises.com/Edu_Classif_Evap.html
Moore, C.H., 2001. Carbonate reservoirs porosity evolution and diagenesis in a sequence stratigraphic framework: Amsterdam, Elsevier, 444 pp.
Moradi, M., Moussavi-Harami, R., Mahboubi, A., Khanehbad, M. and Ghabeishavi, A., 2017. Rock typing using geological and petrophysical data in the Asmari reservoir, Aghajari Oilfield, SW Iran. Journal of Petroleum Science and Engineering, 152: 523-537.
Mossadegh, Z.K., Haig, D.W., Allan, T., Adabi, M.H. and Sadeghi, A., 2009. Salinity changes during late Oligocene to early Miocene Asmari formation deposition, Zagros Mountains, Iran. Palaeogeography, Palaeoclimatology, Palaeoecology, 272(1-2): 17-36.
Motiei, H., 1993. Stratigraphy of the Zagros, Treatise on the geology of Iran,Ministry of Mines and Metals, Geological Survey of Iran, Tehran.
Saller, A. H., Henderson, N. 1998. Distribution of porosity and permeability in platform dolomites: Insight from the Permian of west Texas. Association of Petroleum Geologist bulletin, 82 (8): 1528-1550.
Sampo, M. 1969. In: Cuvillier, J. and S churmann, H. M. E. (eds) Microfacies and Microfossils of the Zagros Area Southwestern Iran (From Pre Permian to Miocene). International Sedimentary Petrographical Series. E. J. Brill, Leiden, 12: 1-102.
Scholle, P. A., Halley, R. B. 1985. Burial diagenesis: out of sight, out of mind!
Scholle, P. A., Ulmer-Scholle, D. S. 2003. A Color Guide to the Petrography of Carbonate Rocks: Grains, Textures, Porosity, Diagenesis, American Association of Petroleum Geologists, 77.
Sepehr, M. and Cosgrove, J.W., 2004. Structural framework of the Zagros fold-thrust belt, Iran. Marine and Petroleum Geology, 21(7): 829-843.
Seyrafian, A. and Hamedani, A. 2003. Microfacies and paleoenvironmental interpretation of the lower Asmari Formation (Oligocene), north-central Zagros Basin, Iran. Neues Jahrbuch für Geologie und Paläontologie-Monatshefte, 3: 164-174.
Sherkati, S. and Letouzey, J., 2004. Variation of structural style and basin evolution in the central Zagros (Izeh zone and Dezful Embayment), Iran. Marine and Petroleum Geology, 21 (5): 535-554.

Tucker, M. E., 2001. Sedimentary Petrology: An Introduction to the Origin of Sedimentary Rocks, Wiley.

Tucker, M. Wright, V. P. 1990. Carbonate sediments and limestones: constituents. Carbonate sedimentology. Blackwell, Oxford, 1-27.

Tucker, M.E., 1994. Sedimentary petrology: an introduction to the origin of sedimentary rocks. Blackwell Scientific Publication, 260 pp.

Vail, P.R., 1991. The stratigraphic signatures of tectonics, eustacy and sedimentology-an overview. Cycles and events in stratigraphy. 617-659.

Van Buchem, F.S.P., Allan, T.L., Laursen, G.V., Lotfpour, M., Moallemi, A., Monibi, S., Motiei, H., Pickard, N.A.H., Tahmasbi, A.R., Vedrenne, V. and Vincent, B., 2010. Regional stratigraphic architecture and reservoir types of the Oligo-Miocene deposits in the Dezful Embayment (Asmari and Pabdeh Formations) SW Iran. Geological Society Special Publications, 329 (1): 219-263.

Van Wagoner, J.C., Mitchum, R.M., Campion, K.M. and Rahmanian, V.D., 1990. Siliciclastic sequence stratigraphy in well logs, cores, and outcrops: concepts for high-resolution correlation of time and facies, Association of Petroleum Geologists Methods Exploration. Series. 7: 55p.

Vaziri-Moghaddam, H., Kimiagari, M., Taheri, A., 2006. Depositional environment and sequence stratigraphy of the Oligo-Miocene Asmari Formation in SW Iran. Facies, 52: 41-51.

Warren, J, 2000. Dolomite: Occurrence, evolution and economically important association: Earth Science Review, 52: 1-18

Warren, J, 2000. Evaporites Sediments Resources and Hydrocarbons, Springer Verlag, Berlin, Pp.1053.

Wilson, J. L., 1975. Carbonate facies in geological history: New York, Springer. Pp.471.