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Facies, Sedimentary Environment, Diagenesis and Sequence Stratigraphy of the Ilam Formation in the Darquain Oil Field, Southwest of Iran

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ABSTRACT

The Ilam formation is one of the Bangestan group formation and one of the most important reservoir Rocks in the Zagros basin. This formation mainly consists of limestone with shale interbedded in the Darquain oil field. About 300 microscopic thin sections related to the wells Nos. 32 and 33 of the Darquain oil field were studied for identification of facies and interpretation of sedimentary environment of the Ilam formation. Widespread laboratory studies show that the Ilam formation consists of 6 facies associated with a homoclinal carbonate ramp platform. A third-order sedimentary sequence with two sequence boundary type 2 (SB 2) derived from petrographic studies, facies and petrophysical logs for the Ilam formation. Cementation, dolomitization, dissolution, mechanical and chemical compaction, micritization, pyritization and bioturbation are the most important diagenetic processes in the Ilam formation, which all occurred in marine, atmospheric and burial diagenetic environments. The Ilam formation at Darquain oil field has a porosity more than 5% and more than 10% in most of cores. Permeability is variable between 0.1 to 10 milli Darcy, therefore the reservoir quality of this formation is generally well estimated.

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INTRODUCTION

The quality and architecture of sedimentary carbonate reservoirs depends on multiple factors including spatial distribution of facies, diagenetic processes and deposition cycles (high-frequency and deposition cycles) (Lucia 2007, Ahr 2011).

Primary porosity and distribution of permeability generally controlled by depositional facies in the carbonate reservoirs (Schlager 2005). In the absence of diagenesis changes, the reservoir features controlled by sedimentary facies (in microscopic scale) and sedimentary environment (in macroscopic scale).

The Bangestan group with age of Albian – Campanian is one of the most important hydrocarbon reservoirs in the Arabian platform and the Zagros. The most important intervals of this group include shallow carbonates Rocks of the Sarvak and Ilam formations and its equivalents (like the Mishrif formation in Iraq). Therefore, the Ilam formation and its equivalents are important hydrocarbon reservoirs in the South and Southwest of Iran (including the Dezful embayment and the Abadan plain) and all over the Middle East (Motiei 1993, Ghabeishavi et al. 2009, Rahimpour - Bonab et al. 2012 a, b).

The purpose of this study is to introduce facies, sedimentary environment and present sedimentary model for Ilam formation in Darquain oil field located in the Abadan plain. Also sequence stratigraphy, diagenesis and reservoir quality of this formation have been investigated.

MATERIALS AND METHODS

More than 300 thin sections taken from the wells # 32 and # 33 of the Darquain oil field core samples studied and described using the Dunham method and the Embry and Klovan method. Each thin section is made of a plug. Some thin sections have been stained by Alizarin Red S. to differentiate calcite from dolomite. Facies and sedimentary environment have been interpreted based on value of matrix and grains, fabric elements, fossil content, energy index, sedimentary data comparison with old and modern models such Wilson (Wilson 1975), Tucker and Wright (Tucker and Wright 1990), Wright and Burchette (Wright and Burchette 1996) and Flügel (Flügel 2010). Several factors have been considered for the categorize of sedimentary facies such as pelagic Foraminifera, green algae, sponge spicule, echinoderm, bivalves and skeletal fragments (such as ooid, Peloid, Intraclast) and its accumulations. Using the results of facies and their vertical variations, petrophysical logs (especially gamma Ray logs), paleontology data (such as the frequency ratio of plankton to benthic Foraminifera) as well as the results of biostratigraphy, the main surfaces of the sequence (such as maximum flooding surface), the main sequences of the Ilam formation were identified in the wells studied. Following, the effective diagenetic processes and diagenesis system of the Ilam formation were studied. Also, due to facies, diagenetic processes and petrophysical logs, the reservoir quality of this formation was investigated. It should be noted that for studying the quality of the reservoir, scanning electron microscopy (SEM) photographs and petrophysical logs of wells No. 2, 3, 5, 6 and 21 of the Darquain oil field have been used.

RESULTS AND DISCUSSION

Geological setting

The thick sequences of sediments deposited during the Cretaceous period have been recorded geological history of the Arabian platform and the Zagros folded belt (including the Dezful embayment and the Mesopotamian basin) (Al-Sharhan and Nairn 1993, Ghabeishavi et al. 2009, Hollis 2011). A significant part of the world's hydrocarbon reserves and a large number of Middle Eastern oil reserve are in these sequences. A ramp-type sedimentary regime with carbonate shelves proposed in the Early Cretaceous geographical studies which has been associated a relative sea level rise in the Middle East. During this period, the Arabic plate has moved towards tropical and subtropical latitudes (Heydari 2008). At the same time, local diapirisms or the movement of basement blocks intermittently and locally caused the uplift and Epeirogeny of carbonate platforms (Van Buchem et al. 2011, Hollis 2011). The study area was located near the equator in the Northern hemisphere and on the Northern domain of this mobile plate along the Late Cretaceous (Heydari 2008, Van Buchem et al. 2011). At the same time, the general configuration of the basin from a passive marginal sedimentary basin, including the shallow shelves and Intra-shelves (extended throughout the Jurassic), occurred to an active marginal ramp system (e.g., Ziegler 2001, Piryaei et al. 2010, Hollis 2011).

The Darquain oil field is part of the Zagros sedimentary basin and the Arabic plate. This area has a North-South trend and is located in the Southwest of the Iran and 40 km North of the Abadan. The length

Fig. 1. Geographical location of the study area in the Southwest of the Iran.

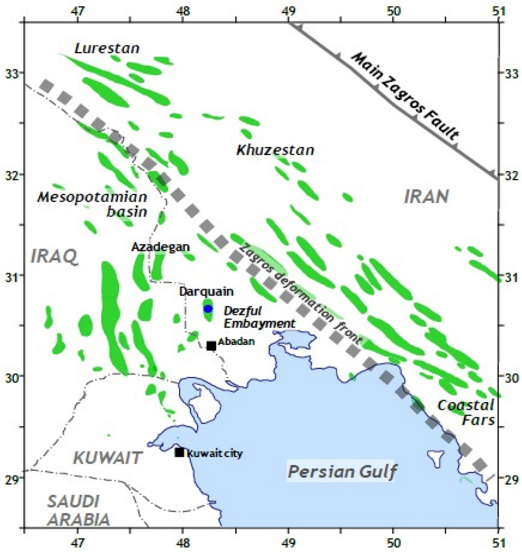

Fig. 2. Geographical location of the Abadan plain and the Darquain oil field.

of its structure is 24 km and its width is 10 km (Figs. 1 and 2).

Today's boundaries of the Arabian plate include all types of tectonic regimes. The basin includes the Persian Gulf, the entire Western and Southern regions of the Zagros Mountains, the Arabian Peninsula, Iraq, Jordan, Syria and the Southeast Turkey. The Zagros Mountains are located in the Northeastern of the Arabic plate. This plate is limited by the Zagros main thrust fault (ZMTF), in the North-West by the Dead sea fault zone (DSFZ), in the Southwest by the Red Sea rift and in the Southeast by the Indian Ocean (Heydari 2008).

The Darquain structure is an anticline from an anticline strip which started from the Kuwait and the Saudi Arabia toward the Southwest of the Zagros' anticlines gradually disappear (Motiei 1993). The Ilam formation in the Southwest of the Iran has two facies, deep facies in the Lorestan region and shallow marine facies in the Fars and the Dezful embayment. The type section is measured at the North of Kabir Kouth, 12 km from the Ilam city. The Ilam formation includes 190 m of fine-grain pelagic gray argillaceous limestone, with regular layering and thin shale inter-

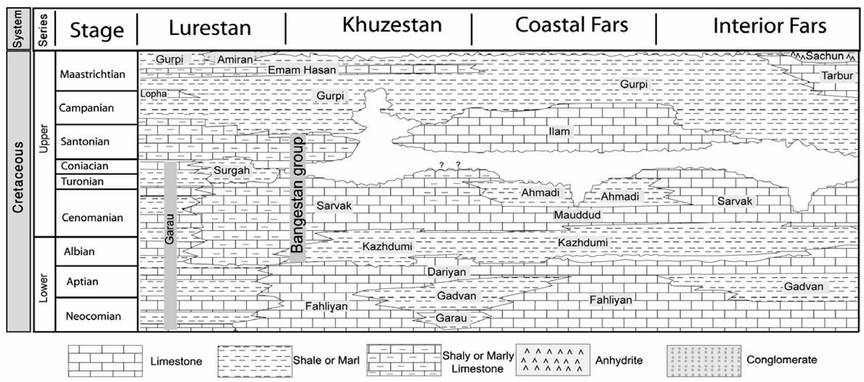

Fig. 3. Relationship of the Ilam formation in the Lorestan, Khuzestan, Coastal Fars and Interior Fars (adapted from Jamies and Waynd 1965).

bedded and the age of Santonian to Campanian in this section, the Sarvak formation is generally below the Ilam formation. The Surgah formation separates the Sarvak and the Ilam formations from each other in the Lorestan area (Fig. 3). The Darquain oil field is part of the Zagros sedimentary basin and the Arabian plate. This field with North-South trend is located in the Southwestern of the Iran, about 5 km North of the Abadan, with a length of 40 and width of 10 km (Figs. 1 and 2).

The Ilam formation in the Darquain oil field generally includes limestone and shale interbedded. The upper boundary of this formation with the Gurpi formation is gradual and its boundary to the Surgah formation is sudden and sharp. The age of this formation is equivalent to the Santonian-Campanian stage (Motiei 1993). The average thickness of the Ilam formation in the Darquain oil field is about 90 m.

Facies description

The Ilam formation in the Darquain oil field consists of 6 facies as follows:

MF1: Bioclast Lime mudstone

This facies has less than 10% of allochems. Planktonic Foraminifera are the most abundant allochems of this facies and mainly consisted of the following gender and species (Fig. 4A): *Marginotruncana* sp., *Heterohelix* sp., *Globotruncana* sp., *Rotalia skourensis, Calcisphaerolla innominatea*. Peloid is another allochems that has been observed with a low frequency in the context of the mudstone texture of this facies. The presence of anoxic minerals, organic matter and mineral pyrite is other specifications of this facies. Compaction and dolomitization are the most important diagenetic processes in this facies. It is worth noting that in some samples, bioturbation is also observed.

MF2: Oligosteginid wackestone

The main components of this facies mainly consists of Oligosteginid, plankton and benthic and micro peloid (Fig. 4B). The microfossils of this facies are mainly consisted of the following gender and species: *Oligostegina* sp., *Calcisphaerolla innominata*, *Heterohelix* sp., *Globotruncana* sp., *Marginotruncana* sp. The presence of pyrite mineral, organic matter and mud support fabric is another feature of this facies. Moldic porosity, fracturing, micritization, chemical and physical compaction are the most important diagenetic processes in this facies. It is worth noting that in some samples, stylolites are filled with micro-spray and drusy cements. Oil stain is also observed in this facies.

MF3: Bioclastic wackestone

This facies is mainly composed of different types of bioclasts, including bivalve, gastropod, calcareous sponge spicule, echinoderm components and fine peloid (Fig. 4C). The microfossils of this facies are mainly consisted of the following gender and species: *Marginotruncana* sp., *Heterohelix* sp., *Globotruncana* sp., *Rotalia skourensis*., *Calcisphaerolla innominate*. The abundance of fine echinoderms, the presence of plankton and benthic Foraminifera, fine bioclasts and mud-supported fabric are other features of this facies. Anoxic minerals and pyrite are also found in this facies. Bioturbation, moldic and vuggy porosity, fracturing, chemical and physical compaction are the most important diagenetic processes in this facies. Fractures are mainly filled with calcite cement. The rate of bioturbation in this facies is significant. It is worth noting that the oil stain is also observed in this facies.

MF4: Bioclastic packstone

Skeletal fragments make up the most allochems of this facies. The main allochems of this facies are mainly planktonic and benthic Foraminifera, echinoderm fragments, bivalve, gastropod and ostracod (Fig. 4D). The microfossils of this facies are mainly consisted of the following gender and species: *Rotalia skourensis, Heterohelix* sp., *Marginotruncana* sp., *Globotruncana* sp. Compared to facies number 3 (MF3), in this facies, the volume of bioclasts are more and coarser and the facies has less mud. Compared to facies number 3 (MF3), in this facies, the volume of bioclasts are more and coarser and the facies has less mud. Moldic and vuggy porosity, mostly fine fractures, bioturbation, micritization, pyritization, calcite cement, physical

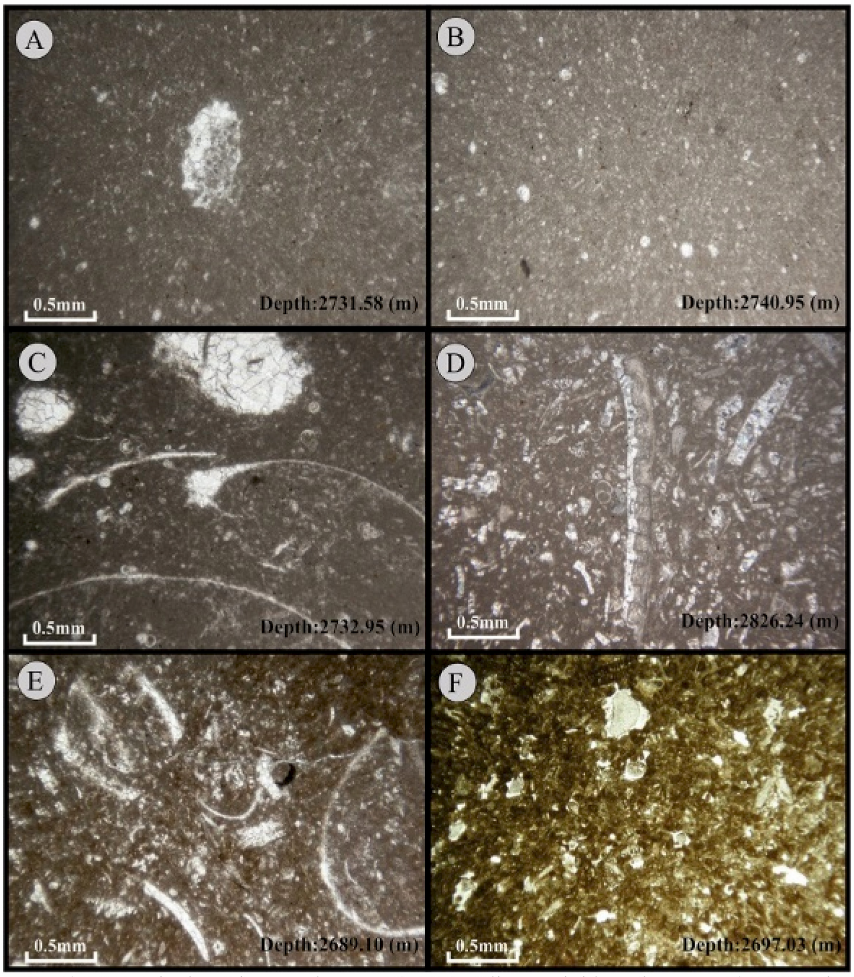

Fig. 4. A) MF1: Bioclast Lime mudstone. B) MF2: Oligosteginid wackestone. C) MF3: Bioclastic wackestone. D) MF4: Bioclastic packstone. E) MF5: Bioclastic, peloid packstone. F) MF 6: Echinoid peloid grainstone / packstone.

and chemical compaction are the most important diagenetic processes in this facies. Fine fractures are the main index of the Ilam formation. In these fractures, oil stain can be observed.

MF5: Bioclast peloidal packstone

This facies mainly consists of peloid, bioclasts and plankton and benthic Foraminifera (Fig. 4E). Its foraminifers are mainly composed of the following gender and species: *Heterohelix* sp., *Rotalia skourensis*, *Marginotruncana* sp., *Globotruncana* sp., *Calcisphaerolla innominata*. Usually, peloides are seen with micritized bioclasts and small benthic Foraminifera. Most bioclasts consist of echinoderm and bivalve fragments. Its fabric is mud supported. Moldic and vuggy porosity, compaction, spray and blocky cement, micritization and anhydrite are the most important diagenetic processes in this facies.

MF6: Echinoid peloidal grainstone to packstone

This facies mainly consists of peloid and bioclasts, plankton and benthic Foraminifera (Fig. 4F). Bioclasts are mainly composed of echinoderm fragments. Its foraminifers are composed of the following gender

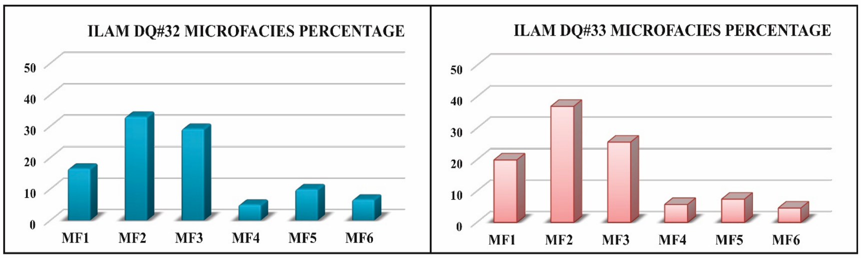

Fig. 5. The frequency diagram of the Ilam formation facies in wells Nos. 32 and 33 of the Darquain oil field.

and species: *Rotalia skourensis*, *Globotruncana* sp., *Textularia* sp. Peloides are commonly seen in with micritized bioclasts and benthic Foraminifera. The grain-supported fabric and a good sorting of grains are the other features of this facies. Moldic and vuggy porosity, physical compaction, syntaxial cement, micritization and anhydrite are the most important diagenetic processes in this facies.

Facies interpretation

The echinoderm fragments and plankton Foraminifera are the main allochems facies of MF1, MF2 and MF3. The presence of these allochems, organic matter, pyrite mineral and mud-supported fabric in these facies indicate that they are formed in an environment with the conditions low energy below the normal wave base in the outer ramp of the sedimentary basin. Low-energy hydrodynamic regime indicates deposition below the normal wave base (Wilson 1975, Flügel 2010). MF1 and MF2 facies can be considered equivalent to Flügel (2010) Facies (RMF) No. 3 and MF3 facies can be considered equivalent to Flügel (2010) Facies (RMF) No. 4. Mehrabi and Rahimpour–Bonab (2014) similar facies MF1 and MF2 and Rahimpour–Bonab et al. (2012b) similar facies MF3 have introduced for the Ilam formation at the Abteymour oil field.

The presence of plankton and benthic Foraminifera, echinoderm fragments, bivalves and mud-supported in the MF4 and MF5 facies indicate. These facies in higher energy conditions than previous facies and are formed in the outer ramp to the mid-ramp of the sedimentary basin.

These facies can be considered equivalent to Flügel (2010) Facies (RMF) Number 4. Rahimpour–Bonab et al. (2012b) similar have introduced these facies for the Ilam formation at the Abteymour oil field.

The presence of plankton and benthic Foraminifera with the peloid and bioclasts, the mud-supported fabric and the relatively good sorting of grains in facies (MF6) No. 6, show that this facies is appeared in relatively high energy environmental conditions and within the middle part of the mid-ramp of the sedimentary basin. This facies can be considered equivalent to Flügel (2010) Facies (RMF) Number 7.

Sedimentary model

Facies and depositional environment analysis of the Ilam formation were the subjects of several studies in various parts of the South and Southwest of the Iran (including the Dezful embayment).

Van Buchem et al. (2006) in their studies of Cretaceous sediments in the Middle East identified that the Ilam formation carbonates were deposited in shallow water ramps with dimensions of more than tens of kilometers in size during the transgressive phase.

Adabi and Mehmandosti (2008) studied the facies and geochemistry of the Ilam formation in the Tang Rashid Izeh (Zagros) area and presented four facies belts tidal flat, lagoon, shoal and open sea belt formed in a ramp platform for this formation.

Ghabeishavi et al. (2009) distinguished 9 facies types formed in continental lacustrine to very shallow and relatively deep-water (hemipelagic to pelagic) marine environments for the Ilam succession in the

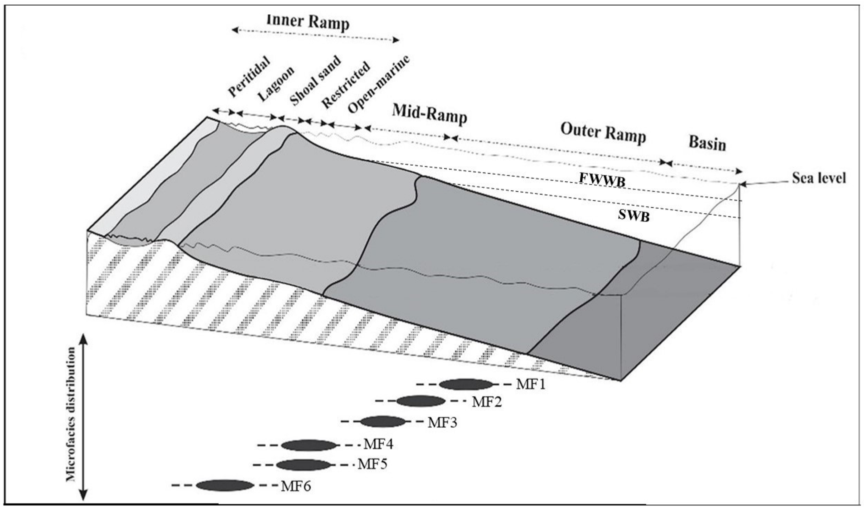

Fig. 6. The proposed sedimentary model for the Ilam formation in the Darquain oil field (adapted from the Burchette and Wright standard model 1992).

Bangestan anticline (Zagros).

The influence of the Late Cretaceous tectonic events on the sedimentation patterns along the North-eastern margin of the Arabian plate (Fars province, Sw Iran) was studied by Piryaei et al. (2010).

According to this study, the Ilam formation in the Fars area was formed in a distally steepened ramp at the end in an ancient Foreland basin. During the Late Cretaceous, intensive tectonic activities in the NE margin of the Arabian plate resulted in severe evolution in the depositional environment of carbonate platforms (both in regional and local scales). According to many researchers, the Cretaceous carbonate platforms of the Middle East (and almost all over the world) were ramp-like. In some cases, geological activities have led to the evolution of these platforms into form distally steepened ramps.

In other cases, they have been rimmed by ooid-barriers, which have been accompanied by the formation of relatively shallow lagoons behind these barriers. However, in the studied interval, lagoon facies are scarce. According to the Ilam formation facies, it can be concluded that the sedimentary environment of this formation is significantly different from that of the Sarvak formation. In most cases, lagoon facies are not seen in the Ilam formation. This indicates the absence of a barrier in the Ilam formation. In addition, aggregations of rudist reefs in the Ilam formation have not been observed. In general, the abundance of these facies in the Ilam formation is much less than the Sarvak formation (Rahimpour–Bonab et al. 2012a, b).

After studying thin sections, 6 facies related to the mid-ramp and outer ramp for the Ilam formation were identified and determined. The facies detected were compared with the various samples of Flügel (2010). Then, the abundance percentage diagram (Fig. 5) and the vertical changes of the Ilam formation facies related to wells numbers 32 and 33 the Darquain oil field were plotted (Figs. 6–8).

Due to the absence of reef structures, cortoid, oncoid, pisoid and aggregate grains that are related to carbonate shelves or rarely found in carbonate ramps (Flügel 2010), the absence of extensive parts and shallow bioclasts of in deep zones, that are characteristic of carbonate rocks (Flügel 2010, Tucker and Wright 1990). Also, the absence of collapsing and slipping structures indicating a high slope of sedimentary environments during sedimentation, gradual change and non-diversity of facies, the sedimentary environment of the Ilam formation in the investigated area, was detected as a carbonate platform of homoclinal ramp type.

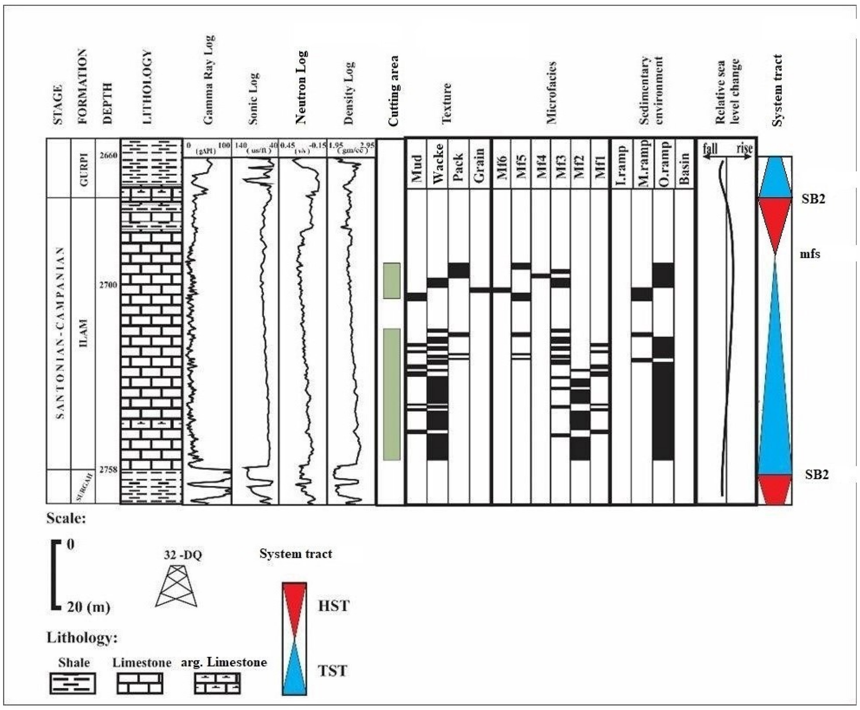

Fig. 7. The sequence stratigraphy of wells Nos. 32 of the Darquain oil field using vertical dispersion of facies and petrophysical logs.

The frequency diagram of the Ilam formation facies (Fig. 5) related to wells Nos. 32 and 33 of the Darquain oil field, shows that the abundance of mud-supported facies in this formation is much more than grain-supported facies and the sediments of this formation are mainly deposited in a relatively low-energy environment. Based on the obtained results and evidence available, the proposed sedimentary model for the Ilam formation in the Darquain oil field is presented using the Burchette and Wright standard model (1992) (Fig. 6).

Sequence stratigraphy

The study of sequence stratigraphic of the Ilam formation has been done by studying cores, thin sections, facies columns and petrophysical logs. In this study, by investigating the facies and their changes in the facies column and using the petrophysical logs and paleontology data, the sequence stratigraphy of the Ilam formation in the Darquain oil field was identified. According to the available evidence, a third-order sedimentary sequence for the Ilam formation in the study area was identified. This sequence with Santonian - Campanian age includes the whole the Ilam formation.

Sedimentary sequence of the Ilam formation

Significant decrease of API in Gamma - Ray log and the sudden increase in sonic, neutron and density logs at the base of the Ilam formation in wells Nos. 32 and 33 of the Darquain oil field shows that the relative sea-level was low during sedimentation in this area.

The bottom boundary of Ilam formation with the Surgah formation is limited by a sequence boundary type 2 (Figs. 7 and 8).

The transgressive systems tract (TST) include generation-related sedimentary units that extend during rapid of sea-level rise (Miall 2010). Increasing planktonic Foraminifera upward, indicating that the basin is deepening and the relative sea level rise. In the Gamma-Ray log slightly variations are observed upward in the API, but in the density log, the measurement unit decreases and in the sonic and neutron logs, there is an increasing trend. This section

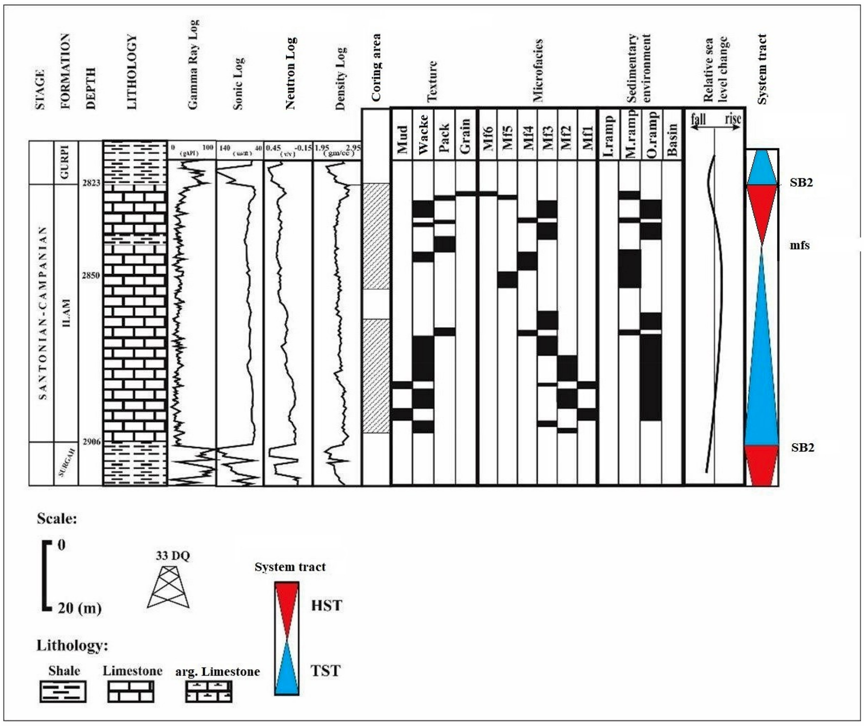

Fig. 8. The sequence stratigraphy of wells Nos. 33 of the Darquain oil field using vertical dispersion of facies and petrophysical logs.

mainly consists facies of MF1, MF2 and MF3, which is related to the outer ramp and contain a significant thickness of the Ilam formation.

At the end of the transgressive systems tract (TST), variations the density log is at a low level and variations the sonic and neutron logs are at the upper limit (porosity reduction). In this system, are mainly observed the outer ramp facies.

The increasing and decreasing trends in the logs and the presence of outer ramp facies represent the maximum flooding surface (mfs) (Figs. 7 and 8).

Highstand system tract (HST) include generation-related sedimentary units that extend at the end of sea-level rise (Miall 2010). This system tract in the Ilam formation has a little thickness in this area. After the maximum flooding surface, the outer ramp facies gradually changes to the mid-ramp facies. The abundance of plankton Foraminifera in this system decreases. Main facies in this system tract include MF 3, MF4, MF5 and MF 6 facies. The process of changing facies from the start of the highstand system tract toward the sequence boundary, from MF3 to the MF6, shows that the basin gradually became shallow. The density log has an increasing trend and neutron and sonic logs have a decreasing trend towards the top of Ilam formation, which represents a porosity increase due to sea level fall. Finally, this system tract is limited at the end by a sequence boundary type 2.

This boundary corresponds to the Ilam and Gurpi formations boundary (Figs. 7 and 8). The thickness of the transgressive systems tract and highstand system tract of both wells is almost equal.

Diagenesis processes

The study of diagenesis processes was performed using thin sections petrography and cores description. The most important diagenetic processes identified in the Ilam formation include cementation in various diagenesis environments, physical and chemical compaction, micritization, dissolution, bioturbation

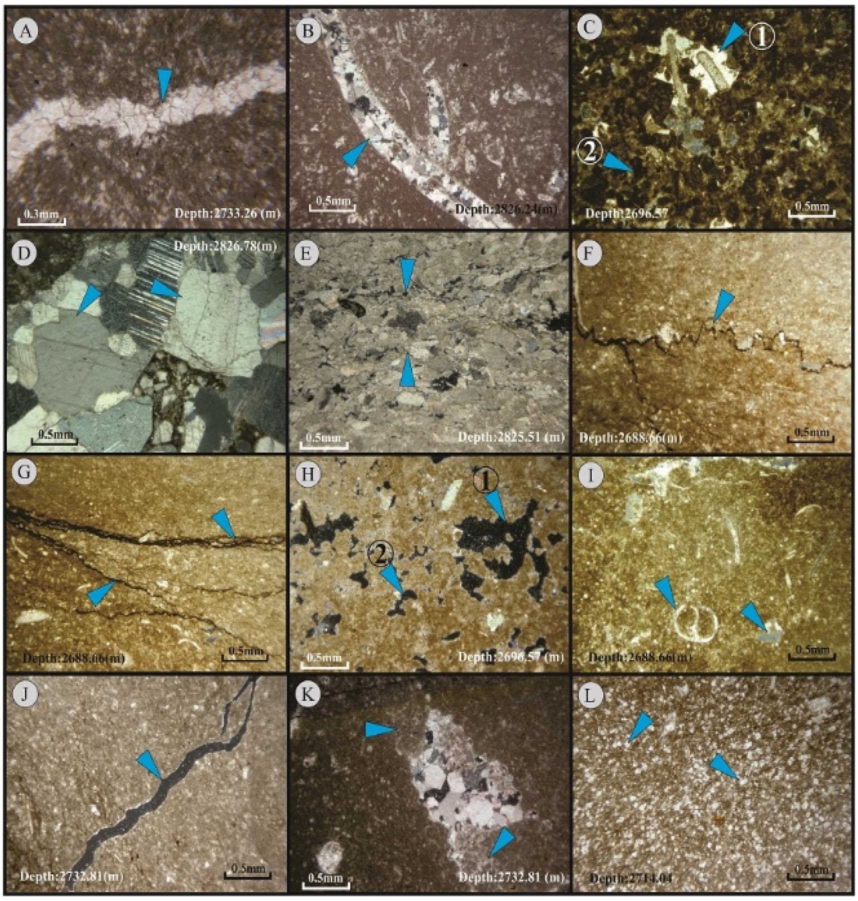

Fig. 9. A: Equant calcite cement (normal light). B: Drusy cement, inside fracture (polarized light). C: (1) Syntaxial cement, around the echinoid fragments (2-Micritization). D: Coarse sparry equant calcite cement (polarized light), fills empty spaces inside the cavities and molds of the components. E: Physical compaction that leads to deform of echinoderm. F: Rock fabric is cut off by stylolite. G: The dissolution sutures are cut off by the Rock fabric and are probably filled with dark-colored bituminous materials. H: (polarized light) (1: Vuggy porosity, 2: Intergranular porosity). I: Moldic porosity. J: Fracture porosity. K: Bioturbation in the Rock fabric is filled with drusy cement (polarized light). L: Replacement of dolomite crystals in the micrite, (polarized light).

and dolomitization. Compaction and compression dissolution has led to the development of stylo lites, dissolution of the sutures and fractures. In the wells studied, these processes have affected the Ilam formation. Cementation is one of the most important diagenesis processes observed in the Ilam formation. Calcite cements fill most of the veins and fractures created in the Ilam formation (in the Darquain oil field) and as a consequence are the most important factors in reducing porosity and permeability in the Ilam formation. Equant calcite cement, Drusy cement, Syntaxial cement and Coarse sparry equant calcite cement, are the most important of cements that observed in the Ilam formation in the Darquain oil field (Fig. 9A, B, C1 and D).

The most important observed effect of physical compaction in Ilam formation in the Darquain oil field is the elongation of the bioclasts parallel to the layering and perpendicular to the direction of pressure (Fig. 9E).

Due to the burial of sediments up to several thousand meters, chemical compression has caused phenomena's such as the dissolution of the sutures and then stylolites in different facies of the Ilam formation in the Darquain oil field (Fig. 9F and G). The stylolites observed in this formation are often closely associated with burial dolomites and hydrocarbon materials.

In the samples from the Ilam formation, micrite coating is often created around some skeletal grains and it has partly destroyed their primary structure (Fig. 9C2). The most type of porosity in the cores taken from the Ilam formation is intergranular, cavity and moldic, which are observed in all thickness of this formation. In facies with intense leaching and meteoric diagenesis, the porosity of the vuggy (Fig. 9H1), the intergranular (Fig. 9H2) and the moldic (Fig. 9I) extends and in the layers with the highest compaction, the porosity of the fracture (Fig. 9J) is observed.

In the Ilam formation, in the Darquain oil field, there are generally no high dissolution and less cemented zones, which provide good reservoir quality. The presence of stylolite and vuggy porosities in the Ilam formation in this area, indicates dissolution in burial diagenetic environments.

Bioturbation and micritization have no significant effect on the pore stone's pore and reservoir quality (Fig. 9K). Bioturbation has mainly been observed in the facies of the mid and outer ramp environment of the Ilam formation in the Darquain oil field.

Petrographic studies on the cores of the Ilam formation in the Darquain oil field show that the dolomitization process has often been occurred randomly selective in this formation and the pervasive dolomitization in its samples is less. Dolomitization in the Ilam formation has often occurred in the form of a replacement of dolomite rhombohedral crystals in the fine crystalline background of Rock, dissolved moldic skeletal components, or dolomitization along the stylolite's surface (Fig. 9L). Despite the observation of the intergranular porosity in some cores, generally due to its not significant development and also the dominate mud-supported facies, dolomitization in the Ilam formation in the Darquain oil field has not had a significant effect on the reservoir quality of this formation.

Paragenetic succession

The identification of diagenetic processes obtained from petrographic studies shows that limestone of the Ilam formation in the Darquain oil field has been affected by three marine, meteoric and burial diagenesis environments, consequently, various diagenesis processes have been applied to sediments of this formation. The diagenetic stages affecting the Ilam formation are as follows:

***Primary diagenetic stage*:** The most important diagenetic processes in this stage include the forming of equant calcite cement, micritization, boring, bioturbation and physical compaction. Micritization is a common phenomenon in lagoon environments and is occurred by microbial agents. Micritization of the grains shows that the calcareous sediments of the Ilam formation in the study area are initially affected by marine waters.

***Intermediate diagenetic stage*:** Diagenetic processes of this stage have been created during the burial of sediments and increase of pressure and temperature. These processes include calcite block cement, marginal synthetic cement, neomorphism, physical and chemical compaction, dolomitization, pyritization and dissolution. The development of burial diagenetic environment cements such as clean syntaxial cement, forming stylolite, dissolution sutures are evidence of the effect of the burial diagenesis on the Ilam formation in the Darquain oil field.

***The final diagenetic stage*:** At this stage, the sutures, fractures, faults and dissolution phenomena are formed due to the uplifting of rocks. These processes are mainly due to by the diagenesis meteoric environment (Fig. 10).

Reservoir quality of the Ilam formation

The major part of the Ilam formation is limestone and dolomitic limestone. Dolomite crystals are euhedral to subhedral and in granular size to very fine (micro) and sporadically observed. This formation has endured intense compaction. The presence of features associated with compaction, such as stylolites and especially dissolution sutures, confirms this. The

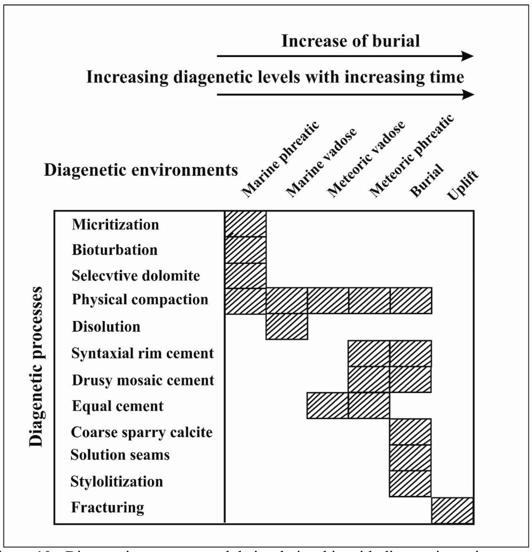

Fig. 10. Diagenesis processes and their relationship with diagenetic environments.

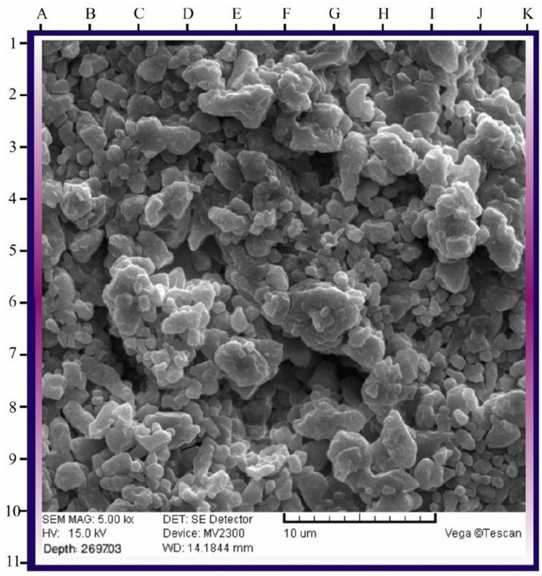

Fig. 12. SEM image of micro-porosity of the Ilam formation in the Darquain oil field.

dissolution sutures and compaction are characteristics of the Ilam formation. There is a direct correlation between compression and dolomitization phenomena in the Ilam formation. The size of the allochems is medium to small (in the size of silt and sand) and often, small skeletal fragments can be observed in the Ilam formation. Most of the fossils are plankton, which represents the sedimentation of this formation in open sea environments. Bioturbation in the whole of the formation is sporadically. Bioturbation in the whole of the formation is sporadically. Neomorphism has had a widespread influence on diagenesis in the whole of the Ilam formation.

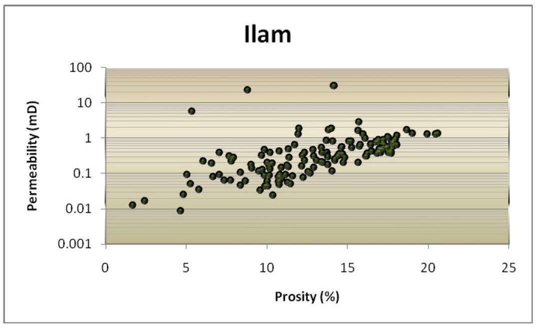

Fig. 11. Porosity and permeability of the Ilam formation in the Darquain oil field.

The dominant facies are skeletal wackestone which are altered upward to wackestone to packstone facies. In some sector, the amount of energy in the sedimentary environment has been very low and leads

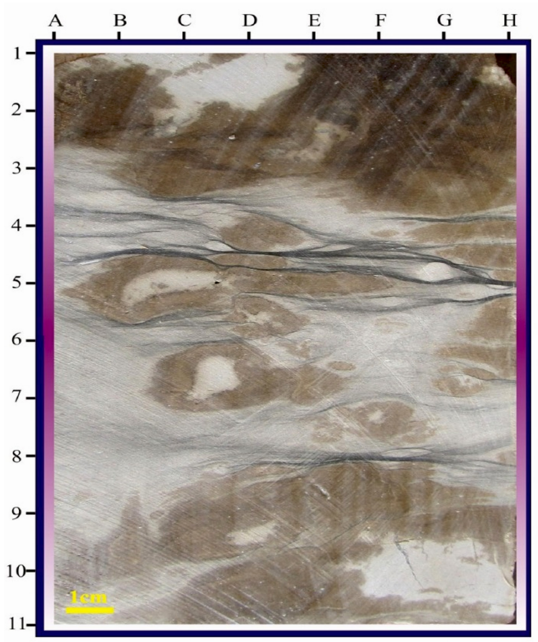

Fig. 13. Oil stains in the Ilam formation, wells Nos. 32, depth: 2722.62 m.

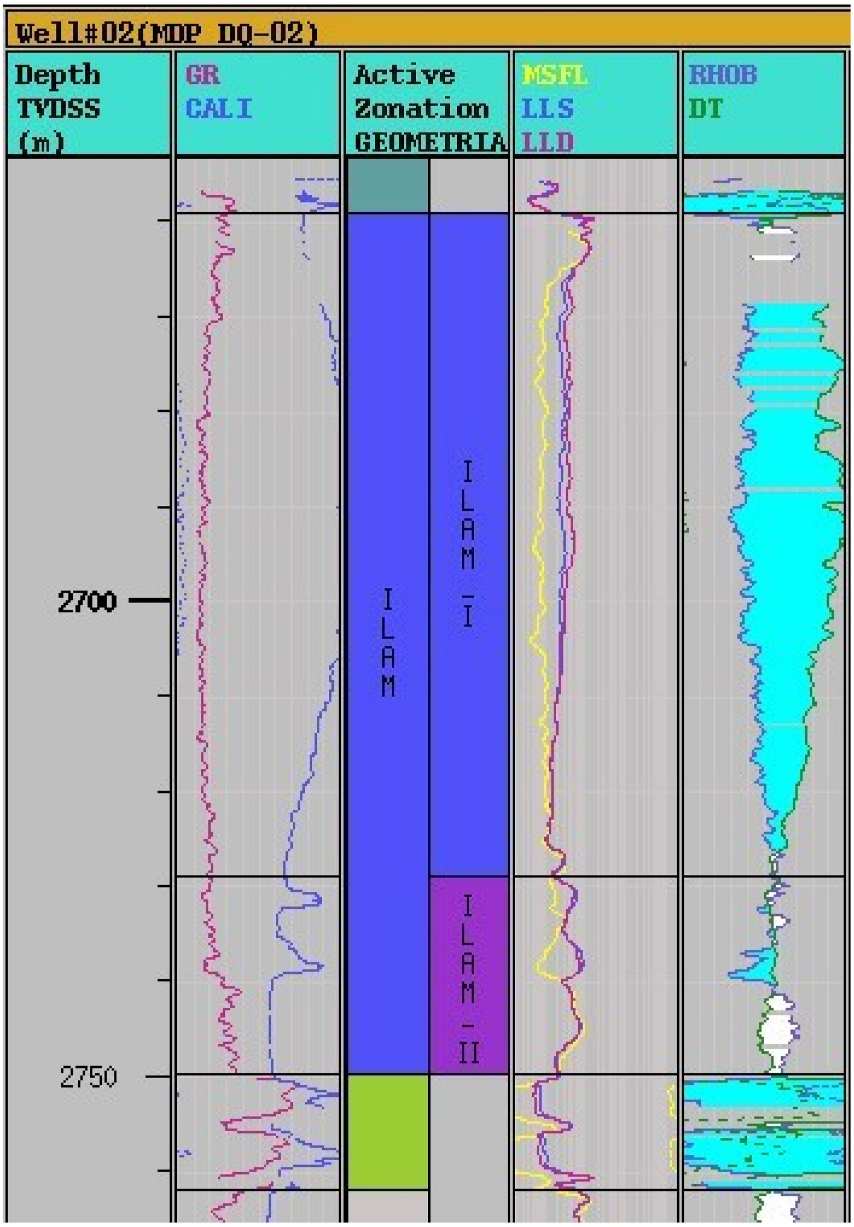

Fig. 14. The Ilam formation zonation using petrophysical logs in the Darquain oil field, wells Nos.21 (National Iranian Oil Company).

to the formation of fossiliferous mudstone facies. The porosity and permeability cross-plot represent this fact (Fig. 11). All the cores have almost porosity more than 5% and most of the cores have more than 10% pores. The permeability of this formation is from 0.01 to 10 milli Darcy, so the quality whole of the reservoir decreases. In fact, the Ilam formation has very good porosity, but the permeability of this formation is not high. This phenomenon results from the fact that most pores are in the size of the micro porosity. The images taken by scanning electron microscopy from the thin sections of the Ilam formation show good the micro porosity and their relationship (Fig. 12). Therefore, the Ilam formation has high porosity and medium to low permeability. Very fine fractures have increased porosity and permeability in some of the cores. The presence of heavy oil stains in some cores makes it difficult to study thin sections. These oil stains are observed sporadically in the cores (Fig. 13).

Considering the characteristics of facies, diagenesis processes, sedimentary environments, porosity and permeability, petrophysical logs data and scanning electron microscopy images, it can be concluded that the quality of reservoir of Ilam formation in the Darquain oil field is relatively good and the Ilam zone I. This formation has good reservoir quality (Fig. 14).

CONCLUSION

The main results of the study on the deposits of the Ilam formation in the Darquain oil field, the Abadan plain (Iran Southwest) can be summarized as follows: The Ilam formation in the Darquain oil field is about 90 m thick. Its lithology mainly consisted of limestone with shale interbedded. Microscopic study of thin sections of wells Nos. 32 and 33 of the Darquain oil field resulted in the identification of 6 carbonate facies in the sequence of the Ilam formation in this field. According to the characteristics of facies the absence of reef structures, cortoid, oncoid, pisoid and aggregate grains, the sedimentary model of the Ilam formation was identified as a homoclinal carbonate ramp. Based on the data obtained from the facies, petrographic studies and the petrophysical logs data a third-order sedimentary sequence with two sequence boundaries type 2 (SB 2) for the Ilam formation in the Darquain oil field were identified. The maximum thickness of sediments of the Ilam formation in the Darquain oil field is related to the highstand system tract (HST). Diagenetic processes of cementation, mechanical and chemical compaction, dissolution, and fracture have the most effect on the Ilam formation in the Darquain oil field. Diagenesis processes of dissolution and fracture caused secondary porosity in the Ilam formation in the Darquain oil field and in relative terms, improved the reservoir quality of this formation. Most of the Ilam formation facies are in the Darquain oil field of mud-supported. This feature has a negative effect on the quality of the reservoir of this formation. Regarding facies, diagenetic processes, petrophysical logs data, porosity and permeability cross-plot and petrography of the Ilam formation in the Darquain oil field, the reservoir quality of this formation was relatively well recognized.

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