Erfani et.al / Iranian Journal of Earth Sciences 8 (2016) / 125-134

The study of diagenetic processes in the Chehel Kaman Formation in the eastern of Kopet-Dagh region, North-East of Iran

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Received 10 March 2015; accepted 11 December 2015

Abstract

The Chehel Kaman Formation of the upper Paleocene age, a carbonate and siliciclastic strata, which is located in the Kapeh-Dagh Basin. Two sections where considered for the purpose of research into the effective diagenetic processes of this formation. The first section, Cheshmeh Qorban, 270.8m thick, located 140km of Mashhad – Sarakhs Highway, while the second section, Shourlaq Section, 288.3 m thick, is situated 130km of Mashhad – Mozduran – Sarakhs Highway. For petrography study, among 120 samples 100 thin sections prepared. As the result of petrography, cementation, micritization, neomorphism, dissolution, and compaction, are the main diagenetic effects. These processes have taken place at the four marine diagenetic stages of the underground and surface fresh water. To indentifying porosity, gypsum wedge has been used. All changes including type and percentage were plotted for each section. The results of the investigations, indicates that the min porosity in the Cheshmeh Qorban section is 3%, max porosity is 7%. In other hand, in the Shourlaq section, the min porosity is 2%, and max porosity is 6%. In the Cheshmeh Qorban section, fracturing, and in the Shourlogh section vuggy is the main type of porosity.

Keywords: *Chehel Kaman Formation, diagenetic processes, Paleocene, porosity.*

1. Introduction

The Chehel Kaman Formation, in the Kapeh Dagh Basin, is mainly comprised of shale and marl limestones in most regions and situated in an isocline manner over the red siliciclastic rocks of the Pesteh Liq Formation and under the marls of the Khangiran Formation (Afshar Harb, 1994; Heydari et al, 2007). Two stratigraphic sections never before investigated and containing the least covering were selected in order to investigate this formation. The Cheshmeh Qorban section with a thickness of 270.8m located 140km down the Mashhad – Sarakhs Highway while the Shourlaq Section with a thickness of 288.3 is situated 130km down the Mashhad – Mozduran – Sarakhs highway (Fig. 1). This formation comprises of three alternating sections of shale and sandstone, limestone interbedded with shale, and shale with limestone investigate the diagenetic processes and the separation of diagenetic environments based on the petrographic studies in the study areas. (Fig. 2).

2. Methodology

To investigate this formation, two stratigraphic sections from the eastern regions of the Cheshmeh Gorban and Shourlaq were measured. The sedimentary sequence was investigated during field surveys with respect to the stratigraphic layers of the sedimentary structures and their biological and non – biological components and 120 samples taken from which 100 cross sections were produced. 21 carbonate and three clastic facies were identified from the investigation of these samples. These cross sections were pigmented by the Dickson method (1965) using potassium ferrocyanide. Pigmentation is performed in order to improve the separation of ferrous limestone from the non-ferrous. The carbonate and clastic rocks were labelled according to the Dunham (1962) and Folk (1980) Classifications respectively.

3. Microfacies

Upper Paleocene deposit of the Chehel kaman Formation in the east Kopet Dagh basin (Cheshmeh Qorban and Shourlog sections) is composed of four carbonate lithofacies belt containing 21 carbonate facies and three siliciclastic lithofacies. These facies were formed in sub-environment that consisted of foreshoal (the mudstone – bioclast wackestone – ooid packstone – intraclast bioclast packstone – ooid bioclast packstone – bioclast packstone), grain – rich shoal (the ooid bioclast grainstone – intraclast bioclast grainstone and the ooid grainstone), semirestricted lagoon (the miliolidea packstone – bioclast packstone – intraclast bioclast packstone –ooid packstone – bioclast wackestone – ooid bioclast wackestone and the

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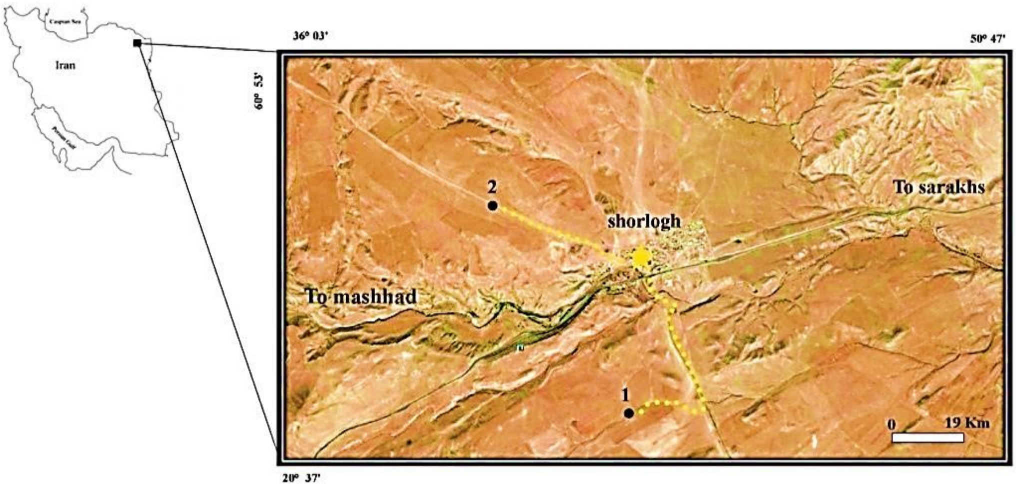

Fig. 1- The location of Cheshmeh Qorban (1) and Shourlog (2) sections, (Google map)

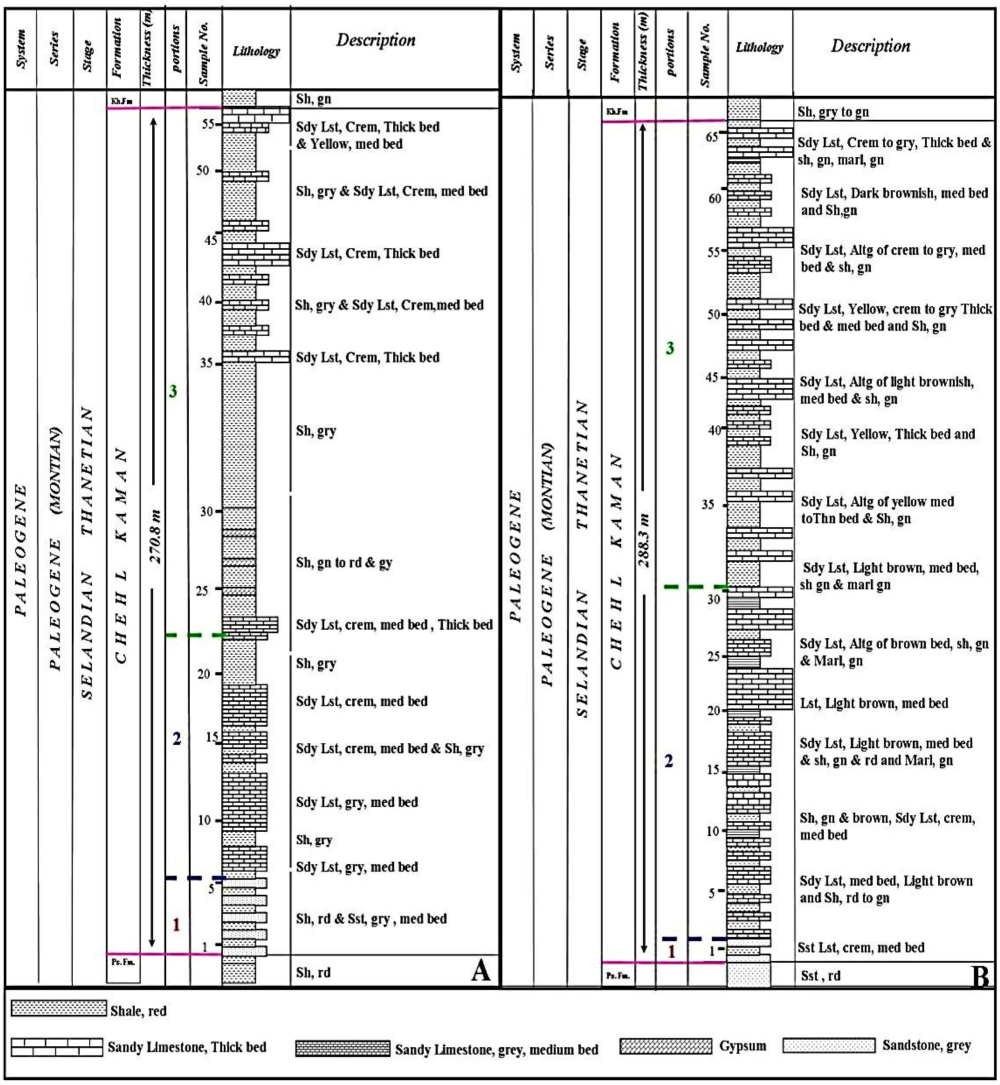

Fig. 2- Two measured sections of Chehel Kaman Formation; A) Cheshmeh Qorban, B) Shourlog

pelloidal bioclast packstone) and tidal flat (the ooid grainstone – intraclast ooid grainstone – peloid ooid grainstone – ooid peloid grainstone and the mudstone) deposits, respectively. Some thick intervals of calcareous shale and fine-to medium-grained sandstone (the quartzarenite – subarkose and arkose) are also present interspersed with these carbonate lithofacies. Lithofacies are deposited in a ramp platform (Erfani et al, 2015).

4. Diagenetic processes

Petrographic investigation of the cross sections of the Chehel Kaman resulted in the identification of a collection of diagenetic processes such as cementation, micritization, neomorphism, dissolution stress, and porosity, each of which is hereby explained for the area under research.

4.1. Cementation

In the Chehel Kaman Formation, in the 2 studied sections, variety of cements have been identified as below:

4.1.1. Isopachous cement

This type of cement is a representation of the cement of the first generation and is deposited around the pebbles in needle and botryoidal forms by sea water (Flugel, 2010). These cements are formed in the primal diagenetic environments (Haijun et al, 2006). Because of their similarity with aragonite cements of warm shallow waters of today, the mineral composition of these cements are also probably aragonite (Adabi & Rao, 1991). This cement is formed inlayers with an identical thickness of less than 0.2 mm. The crystals are seen parallel and perpendicular to the wall of the lime grains such as ooids or skeletal fragments (Honarmand et al, 2012). This type of cement is found in packstone lagoonal and greenstone barrier facies (Fig. 3-A). The aforementioned cement has been responsible for the retention of texture and porosity of the rock and specially the intergranular porosity as a primal cement in the supporting granular facies (Junlong et al, 2015). This type of porosity is considered the best type of porosity as far as it concerns the reservoir features because of their high permeability as well as a high rate of porosity (Lucia, 1995).

4.1.2. Blocky cements

Blocky cements fill the spaces between the grains in the form of large crystals with a reasonably clear verges. This type of cement are formed in burial environments as well as fresh water regions and is considered to be cement of the second or third generation (Tuker, 2001; Haijun et al, 2006; Flugel, 2010). The scatter of the blocky cement is indicative of the lowness of the Mg/Ca ratio in the currents responsible for its formation (Purser, 2006; Ahmad et al, 2006). This cement is occasionally found as the filler in the fractures which can be indicative of their formation in the diagenetic fresh water environment following surfacing (Sling et al, 2005; Honarmand et al, 2012). The blocky cements in the sample under study in the Chehel Kaman Formation are of average size and are mainly found in greenstone facies in intergranular or as fillers of transgranular cavities and lack specific polarity (Fig. 3-B). These cements have been turned blue by potassium ferrocyanide. The aforementioned properties are indicative of iron content in a large quantity of the blocky cements under research formed in fresh water and burial environments (Fig. 3-C).

4.1.3. Equant cement

This type of cement is formed in underground and fresh water diagenetic environments (Choquette & james, 1987; Tucker & Wright, 1990). Identically sized crystals are indicative of the slow growth rate of the low temperature low security CO_3^{2-} and the strength of the CO2 pressure (Tucker, 2001; Mahbobi et al, 2010). This cement is abundant in low temperature atmospheric environments containing low currents with low CO2 content. This cement is found in identically sized mosaics in intergranular spaces in 0.1 to 0.5mm sizes in some packstone lagoonal and greenstone barrier facies in the Chehel Kaman Formation (Fig. 3-D). These cements have been pigmented blue by potassium ferocyanide (Fig. 3-E). The aforementioned properties are indicative of iron content in these cements formed in fresh water and burial environments.

4.1.4. Druzy cements

The crystals in this type of cement are euhedral to subhedral with sizes increasing centripetally (Lopez-Ouiros et al, 2016). This fabric originates from the preferential and competitive growth of calcite on the C Axis and is formed in meteoric and underground deep and shallow marine environments (Flugel, 2010; Tucker & Wright, 1990; Taylor & Machent, 2011). This cement is found mostly in packstone and greenstone facies mainly in the skeletal shells or cavities caused by dissolution (Fig. 3-F). These cements have been turned blue by potassium ferrocyanide which is indicative of iron content (Fig. 3-G). This cement forms in the middle diagenesis stage.

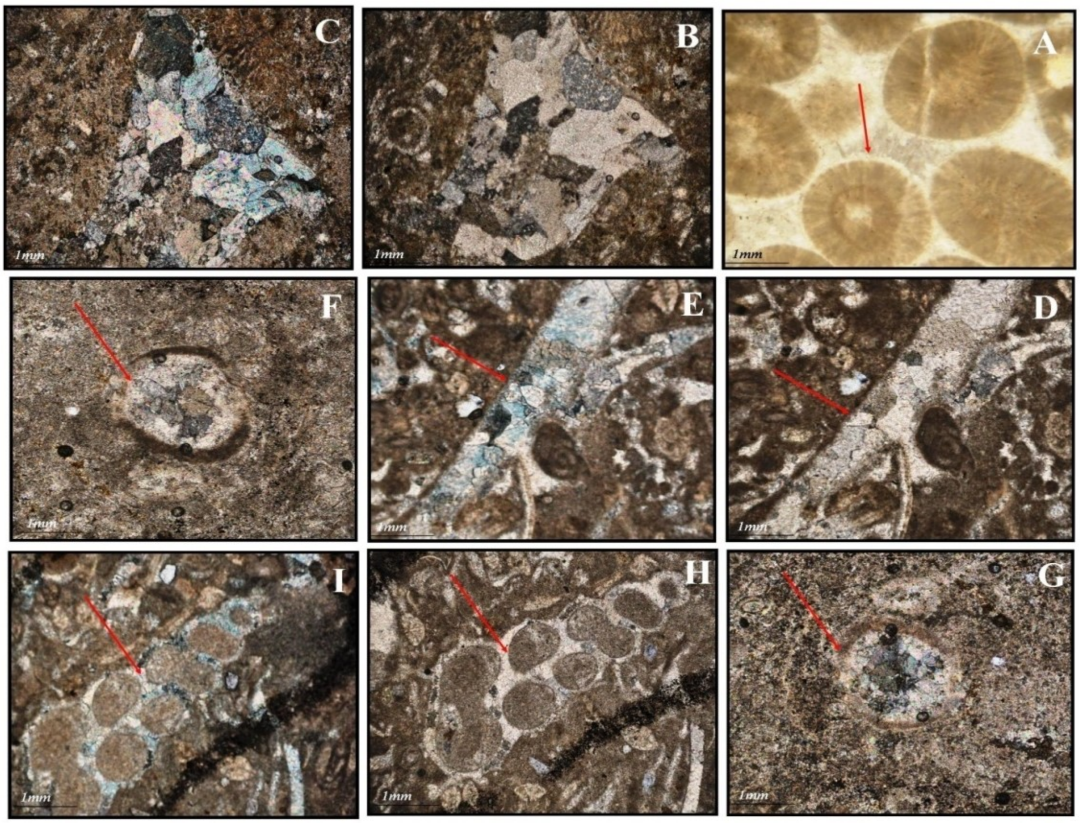

Fig 3: Different cement types in the Chehel Kaman Formation
A) Fibrous cement formed around the grains (red arrow) as the first generation cements. (Grainstones of shoal (XPL), B) Blocky cement formed sparsely within the fragments. Lagoonal packstone (XPL), C) Iron-bearing blocky cement. Sample stained with potassium ferrocyanide. Lagoonal packstone (XPL), D) Equant mosaic cement around fragments (red arrows) (XPL), E) Equant mosaic cement after stained with potassium ferrocyanide (blue cements, red arrows) (XPL), F) Drusy cement filled a bioclast fragment. The crystal size increases towards the center. (Lagoonal packstone) (XPL), G) Drusy cement after stained with potassium ferrocyanide (blue cements, red arrows) Lagoonal packstone (XPL), H) Fine-crystalline blocky cement surrounded the gastropod chamber (red arrow). (Lagoonal bioclast packstone (XPL), I) Fine-crystalline blocky cement stained with potassium ferrocyanide (blue cements, red arrows). Lagoonal bioclast packstone (XPL)

4.2. Micritization

Micritization is a biological process which occurs in the early marine diagenesis stages between the seawater and sediments (Samanckassu et al, 2005). Processes such as microbial activity and sedimentary pulverization result in micritization (Khalifa, et al, 2006). The micritized grains can generally be seen alongside other organisms especially endolithic microbial colonies in low energy shallow marine environments (Ahmad et al, 2006). Algae in many cases dig into and penetrate inside the grains and then activation is followed by micritization (Tucker & wright, 1990; Lopez-Ouiros et al, 2016). The internal micrite membrane of the grains can aid the retention of their shape following dissolution. Most limestone skeletal fragments of the Chehel Kaman Formation including gastropods, brachiopods, and bivalves contain micrite casing. This casing has resulted in the retention of the main fossil shape following neomorphism (Fig. 4-A).

4.3. Neomorphism

This process can be in the form of calcified aragonite bioclasts (Ahmad et al, 2006) or transformation of small –grained crystals into coarse crystals (Flugel, 2010). Neomorphic bioclasts are in many cases indicative of a selective fabric in which cement crystals are only formed in fossil shells leaving the surroundings unchanged (Ahmad et al, 2006; Robert et al, 2013). Respectively, any change in crystal size due to neomorphism can be increasing or decreasing although in most limestones it is increasing (Tucker & Wright, 1990, Tucker, 2001).This process is seen in two forms in samples under research: Gradual transformation of lime mud into coarse crystal sparite in mud facies. Observation of rising neomorphism and their transformation into calcites containing coarser crystals (Fig. 4-B). Transformation of aragonite into calcite in skeletal fragments. Aragonite skeletal shells such as gastropods and bivalves are transformed into calcite crystals by neomorphism and initial aragonite microstructures have been completely destroyed (Fig. 4-C).

4.4. Compaction

Comapction is the accumulation of processes that reduces the volume of massifs and is in two forms: physical and chemical (Flugel, 2010). Many factors including burial depth, mineralogical composition, tissue, grain size, Clay content, pre compression diagenetic transformations, the intergranular water chemistry, and the current direction affect type and the size of compression (Robert et al, 2013; Wolela, 2010). Some evidence of chemical and physical compaction is detected in the samples under research.

5. Physical compaction

Physical compaction occurs because of the weight of the upper layers immediately after sedimentation (Flugel, 2010). This process is identified in the samples under study by the transformation of grains such as ooids, fracture of skeletal shells and intraclasts, and the intermeshing of seed (fig. 4-D). Existence of clay minerals in carbonate rocks delays cementation thus aiding the stress and decrease in porosity (Junlong et al, 2015). Existence of silicon components in grain or cement form enhances the stressed dissolution (Ahmad et al, 2006).

6. Chemical compaction

Physical compaction is followed by chemical compaction or pressure solution and could result in the 20 to 30 percent reduction in the thickness of lime layers. The material necessary for the formation of burial cements is also produced during this process (Lopez-Ouiros et al, 2016; Tucker & Wright, 1990). This type of compaction in the samples under research is evidenced by Convex – concave and serrated intergranular contacts and also the formation of stylolite and dissolution joints.

The extant Convex – concave and serrated surfaces in allochems are mainly seen in packstone facies (Fig. 4-E). Styloliteis formed in average to high depth and are one specific indicative of the underground diagenetic environments (Tucker, 1993; Bod et al, 2000).

7. Dissolution

Passage of carbonated saturated currents through the cavities of the carbonate rocks caused the partial dissolution of the unstable minerals. This process usually takes place in diagenetic.

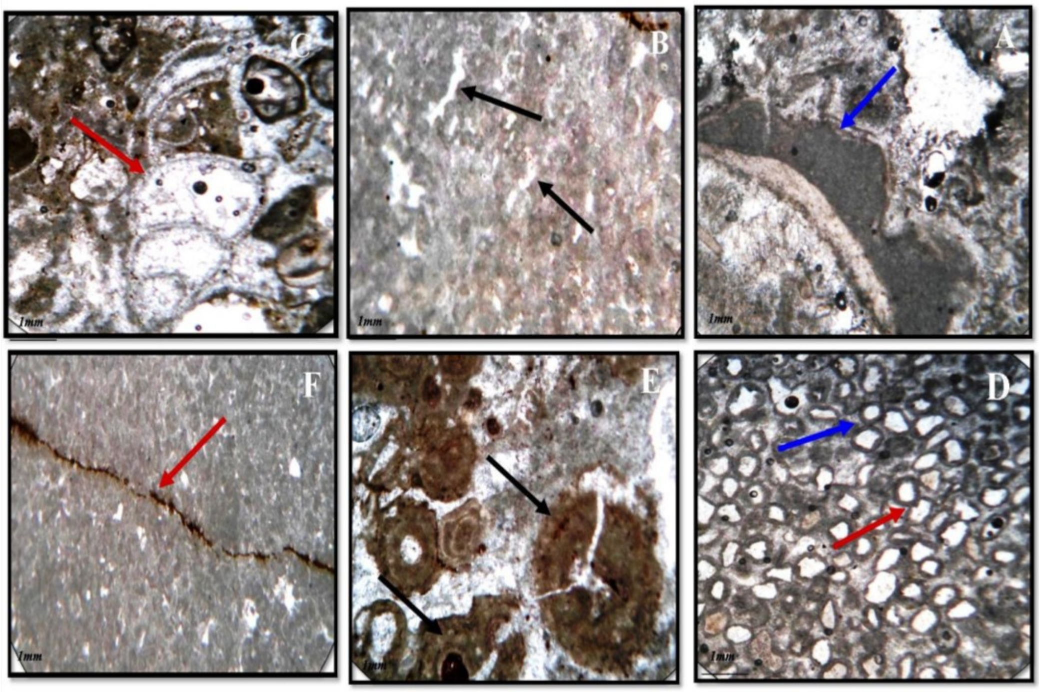

Fig 4: Diagenesis processes in the Chehel Kaman Formation
(A) Micritization in bioclast grainstones of shoal (blue arrow) (XPL). (B) Aggrading neomorphism intidal flat mudstones (black arrow) (XPL). (C) Aggrading neomorphism in a gastropod chamber inlagoonal ooid packstone (red arrow) (XPL). (D) Physical compaction resulted in concavo-convex contacts in a tidal flat ooid grainstone (XPL). (E) Chemical compaction inlagoonal ooid packstone (black arrow) (XPL). (F) Hematite replacement in a stylolite (red arrow) (XPL).

environments in the proximity of the meteoric environment surface and the mixed zone though it can also occur on the sea bed during deep burial and surfacing (Tucker, 2001; Honarmand et al, 2012). The dissolution process has played a fundamental role in the formation of channel and dissolution porosity especially alongside the stylolite in the rock, most of which have been filled with iron oxide (Fig. 4-F). The dissolution index of the carbonates relevant to the effects of fresh water currents and acidity can be regarded as less than 9 (Bostilo & Alonso zarza, 2007).

7.1. Porosity

The carbonated rocks of many of the world's oil and gas fields are formed by solid deposits and water. The contemporary carbonate sediments contain about 60% porosity. The oil and gas filed carbonates usually contain between 8 to 10 percent porosity (Junlong et al, 2015). The dissolution process plays a fundamental role in the formation of porosity in this rock which contains an abundance of porosities according to the Choquette and Pray 1970 Classification. The different porosities extant in the Chehel Kaman Formation are as follows:

7.1.1. Intergranular

This type of porosity includes the intergranular spaces. Grains include all limestone allochems. The shape of these spaces are dependent upon fragment size, meshing, and the arrangement of the grains (Rezaei, 2004; Junlong et al, 2015). This type of porosity is seen between the intraclast ooids (fig. 5-A). The frequency of this type of porosity in the Cheshmeh Qorban and Shourlaq sections is 5% and 4% respectively (Fig. 6, 7).

7.1.2. Intraparticle

This type of porosity exists in the skeletal structure of living organisms such as bryozoan, clams, and corals etc (Choquette & Pray, 1970; Junlong et al, 2015). This porosity can be primal or result from the decomposition of the organic compounds filling the skeletal spaces in lime producing organisms. The size of this porosity is dependent upon the abundance of fossil and non - fossil fragments, size and the type of organism. In the Chehel Kaman Formation this type of fossil is extant in gastropod, ooids and foraminifera cavities (Fig. 5-B). The frequency of this type of porosity in the Cheshmeh Qorban and Shourlaq sections is 5% and 4% respectively (Fig. 6, 7).

7.1.3. Fracturing

This type of porosity occurs as a result of fracture especially in tectonically active regions (Choquette & Pray, 1970). Fractures filled with calcite are evident in the Chehel Kaman Formation. They are members of the non-fabric reliant porosities and are generally the result of implosion tectonic forces or dissolution of calcites and evaporative substances (Fig. 5-C). The frequency of this type of porosity in the Cheshmeh Qorban and Shourlaq sections is 7% and 5% respectively (Fig. 6, 7).

7.1.4. Microporosity

This type of porosities are less than a micron in size and are formed following the deposition of sediments in carbonate rocks. In Chehel Kaman Formation they are formed in mudstones mainly formed in the tidal regions (Fig. 5-D). The frequency of this type of porosity in the Cheshmeh Qorban and Shourlaq sections is 3% and 2% respectively (Fig. 6, 7). Although this type of porosity can be an intergranular porosity, but due to limit this porosity in mud facies was separated.

7.1.5. Moldic porosity

Moldic porosity is formed from the dissolution of one of the rock forming components and retention of the cavity as well as preservation of the original grain form (Choquette & Pray, 1970; Junlong et al, 2015). This type of cement is not so well scattered in the Chehel Kaman Formation and is mainly found in packstone facies (fig. 5-E). The scatter is limited in the Chehel Kaman Formation and is mainly seen in the west section of Shourlaq with a 4% frequency (Fig. 6, 7).

7.1.6. Vuggy porosity

This type of porosity is formed as a result of the specific dissolution diagenetic processes and the enlargement of moldic porosities that can be seen with the naked eye (Rahimpour banab, 2005). This type of porosity is produced as a result of the dissolution of the cement grain or matrix and does not follow the primal fabric (Choquette & Pray, 1970; Junlong et al, 2015). The frequency of this type of porosity in the Cheshmeh Qorban and Shourlaq sections is 4% and 6% respectively (Fig. 5F and. 6,7).

8. Conclusion

The Chehel Kaman Formation of the upper Paleocene age is deposited in a carbonate system. . In order to interpret of diagenetic processes of Chehel-Kaman carbonated formation, two sections as Cheshmeh Ghorban and Shoorlagh were selected in eastern areas. The petrographical studies lead to identify 21 carbonated and 3 silisiclastic facies. This facies are deposited in a ramp carbonate platform according. The carbonate rocks of this system are influenced by diagenetic processes such as cementation, micritization, dissolution, compaction, neomorphism, and porosity. These processes occur in three stages and four marine diagenetic environments of the underground and surface fresh water. The Micritization processes, dissolution neomorphism, and identical blocky cement mosaicking have occurred at marine diagenetic, fresh waterdiagenetic and underground water digenetic stages respectively.

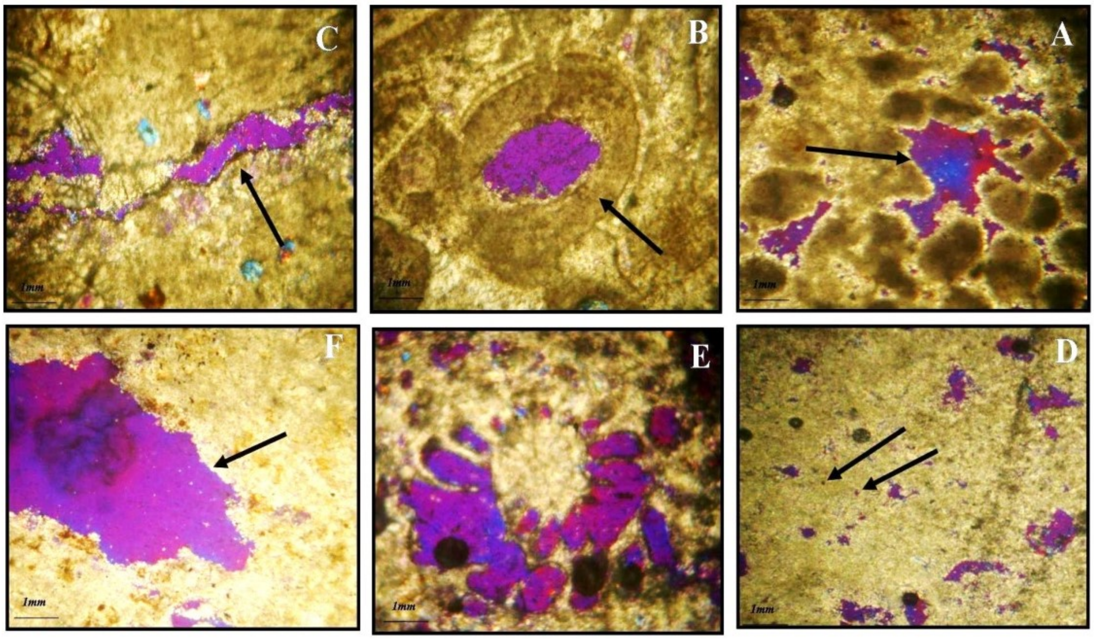

Fig 5: Types of porosity in the Chehel Kaman Formation
(A) Intergranular porosity (between the ooids) inpeloidal ooid grainstone (XPL). (B) Intragranular porosity in Peloidal ooid grainstone (XPL). (C) Fracture porosity in this fracture occurred as a result of fluid flow movements in bioclast grainstone (XPL). (D) Miroporosity inmudstones of tidal flat (XPL). (E) Moldic porosity inlagoonal ooid packstone (XPL). (F) Vuggy porosity in intraclast bioclast grainstones of shoal (XPL).

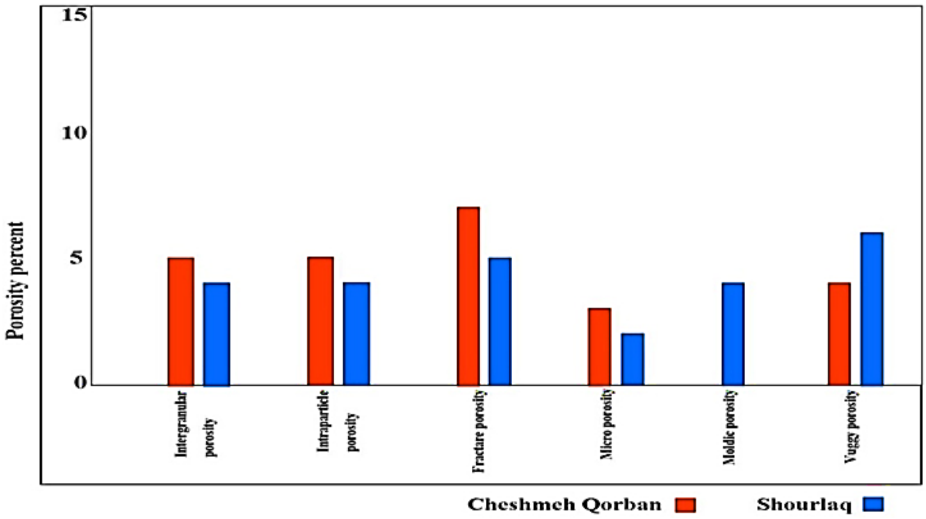

Fig 7: Histogram percent of porosity in two sections

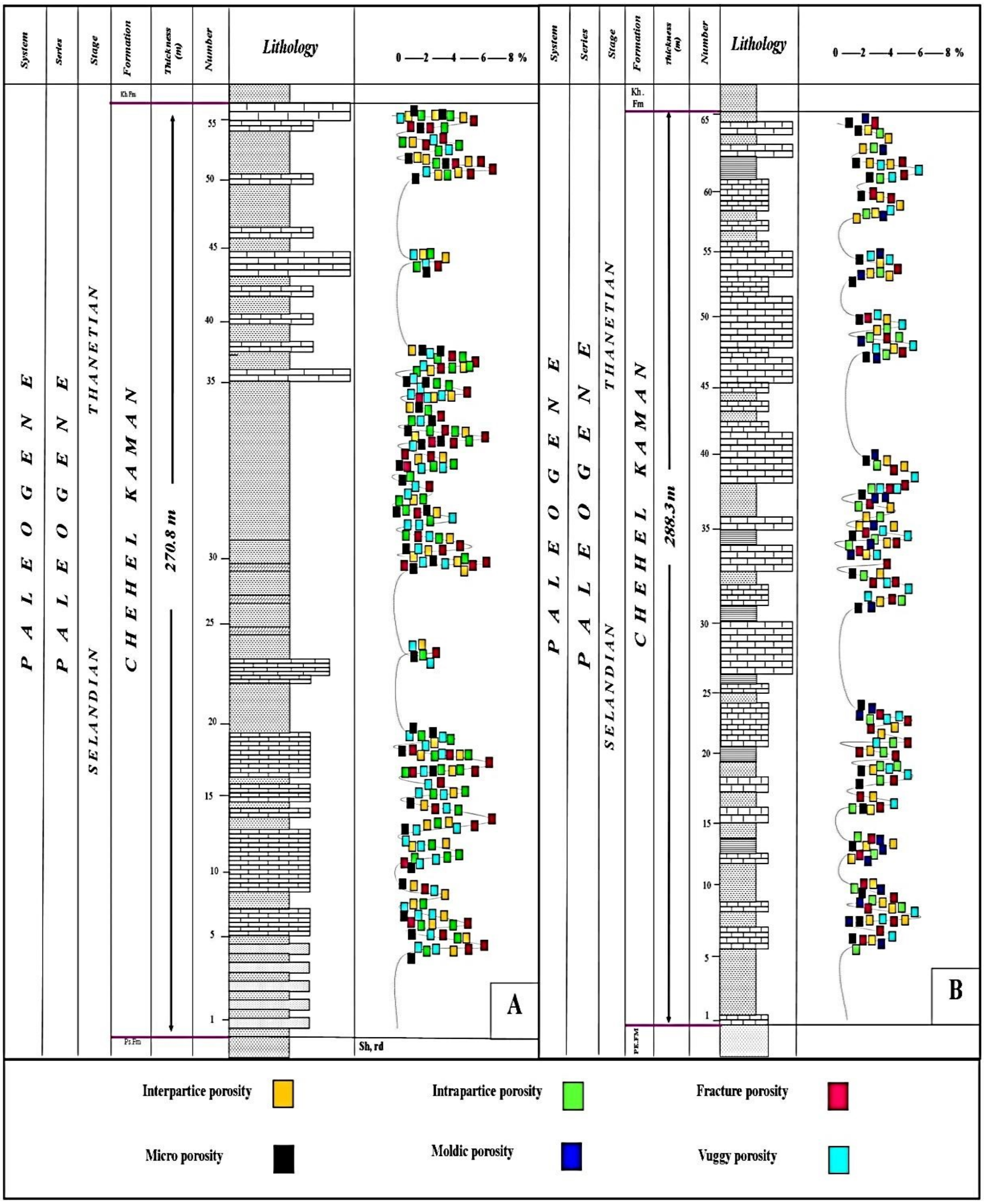

Fig 6: Porosity distribution in two sections A: Cheshmeh Qurban, B: Shorlogh

The cements formed in primal marine diagenetic environments. Blocky and identically sized mosaic cements in this formation are ferrous and have a blue appearance under the microscope and are formed in fresh water and underground water diagenetic environments. The drusy cement is also ferrous and appears blue under the microscope and formed in a diagenetic environment.

The results of the investigations carried out in this formation indicated the frequency of porosity at 5% in the Cheshmeh Qorban section and 4% in the shourlaq Section while the frequency of intergranular porosity in the Cheshmeh Qorban section was at 5% and in the Shourlaq Section at 4%. The results also showed that the frequency of the porosity resultant from fracture to be at 7% in the Cheshmeh Qorban Section and 5% in the Shourlaq Section, Microporosity frequency in the

Cheshmeh Qorban section was measured at 3% while it was at 2% in the Shourlaq Section. The frequency of the vuggy porosity in the Cheshmeh Qorban section was measured at 4% while it was at 6% in the Shourlaq Section. The scatter of moldic porosity was limited in the Chehel Kaman Formation and is observed mainly in the Shourlag Section with a frequency of 4%. These findings indicated that porosity due to fracture had the highest accumulation of porosity with a 7% frequency rate in the Cheshmeh Qorban Section while vuggy porosity had the highest accumulation with a frequency of 6% in the Shourlaq Section. Microporosity was found to be the least accumulated in the Cheshmeh Qorban Section at 3% and in the Shourlaq Section at 2%.

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