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Investigation of reservoir quality of the Kangan Formation based on petrographic and petrophysical studies: A case study of wells "A" and "B" in the gas field of the Tabnak Anticline, SW Iran

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Abstract

The Kangan Formation (Early Triassic) is one of the most important gas reservoirs in the Zagros fold-thrust belt. The study area is located in the west of Hormozgan Province and on the Gavbandi highland. This field is one of the important gas production anticlines in the SW Iran. To investigate the reservoir quality of the Kangan Formation in these wells, 163 microscopic thin sections were prepared from 97.68 m core for petrographic investigations. Then, petrophysical study was out carried using wireline well logs such as spectral gamma ray (SGR), sonic (DT), density (RHOB), and effective porosity (PHIE). The petrographic studies led to the identification of facies features and diagenetic processes affecting the quality of reservoir in the studied wells. These diagenetic processes include chemical and physical compaction, various cementation (especially anhydrite cement), fracturing, dissolution as well as different types of porosity resulting from these processes. Also, for the purpose of accurate evaluation, petrography studies with wells, matching and reservoir characteristics of these wells were qualitatively and quantitatively interpreted and reservoir potential horizons were determined. In general, for the first well (well "A") four and for the second well (well "B") three reservoir horizons were investigated.

Keywords: *Reservoir quality, Petrography, Diagenesis, Well logs, Tabnak Anticline.*

1. Introduction

The Kangan Formation and its equivalent, the Khuff Formation on the Arabian plate, are two the most important reservoirs in the Middle East as well as in the world (Aali et al. 2006; Insalaco et al. 2006). Therefore, facies and diagenesis are the two important factors in the study of the quality of hydrocarbon reservoirs. The reservoir quality of Kangan Formation in this gas field is strongly influenced by diagenetic processes including dissolution and its resulting porosity and the development of marine cement (Nowbahar et al. 2015). Therefore, the purpose of this study was to identify types of diagenetic processes, to interpret the effects of diagenetic processes on the quality of Kangan Formation in these wells and provide a complete description of the conditions of its depositional environment in this field. Hence, the study of petrography and sedimentary facies are required to achieve that. After core description, thin sections were prepared and studied. Using the obtained data, various diagenetic processes of each facies belt affecting the reservoir quality of this formation were investigated. In recent years, extensive studies have been carried out on the Permian-Triassic successions of the Zagros, mainly Kangan Formation in different fields, including: Moradpour et al. (2008); Kavoosi et al. (2011); Tavakkoli et al. (2011); Esrafili-Dizaji et al. (2013); Teymourzadeh et al. (2014); Karimi et al. (2015); Abdolmaleki et al. (2016); Mehrabi et al. (2016); Tavakkoli (2016); Nosrati et al. (2019).

Thus, similar to the objectives of this study, studies have been conducted on other fields in the world, including Morad et al. (2010) on the impact of diagenesis on the heterogenity of reservoirs, Lai et al. (2018) on review of diagenetic facies in tight sandstones: Diagenesis, diagenetic minerals, and prediction via well logs, Behrenbruch et al. (2018) in the Laminaria field- in Australia and Liu and Xie (2018) in the Sichuan Basin- in China. Therefore, it has been attempted to use more studies such as this research in other parts of the world to take more effective steps towards the development and exploitation of the studied field.

2. Geological setting

The geological province of Fars is one of the Zagros folded belt zones (Haynes and McQuillan 1974). The western border of this structural zone is Kazeroon fault and its eastern border is the Zendan fault. The northeast border is limited to the High Zagros fault and the southeastern border corresponds to the Persian Gulf coastline. Some geologists have nominated the southeast section of this zone as the Hinterland of Bandar Abbas and separate it from the Fars zone, but the boundary

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between these two zones is not completely clear and ambiguous (Motiee 1995). Anticlines, such as the Tabnak Anticline with a length of 15 to 20 kilometers, are formed during folding mechanism on the lower disconformity surface (Hormoz salt) and what do you mean? in advanced stages of deformation have been cut off by thrust faults are some of the structural features of this zone (Sherkaty 2005). The anticlines of this region have different orientations. The presence of salt domes and their effect on the anticlines of this zone are considered as important structural features of this region. The geological province of Fars is divided into three sub-sections from north-east to south-west, interior, sub-coastal, and coastal (Alavi 2004). The studied field is located in the coastal Fars and south of the city of Lamerd, parallel to the Persian Gulf coast (Fig 1).

During Triassic time a shallow marine environment, back-arc of the Arabian plate (Kavoosi 2013), results deposition of the Kangan Formation, which was introduced by Harrison (1930) for the first time. The first collection of features and definitions of the lithostratigraphic of the area was prepared by Elder (1957) in reports from 846 and 847 operating companies. James and Wynd (1965) studied the lithostratigraphy and biostratigraphy of the Zagros Permian-Triassic sediments and introduced the formations and biozones. Stocklin (1968) analyzed the history of tectonic Iran and briefly reviewed the sediments of this basin. The Kangan is the name of a city near the Kangan great gas field on the Persian Gulf margin, 175 kilometers south of Bushehr harbor (Setudehnia 1978). The Type section of the Kangan Formation with a thickness of 178 meters (Szabo and Kheradpir 1977) is located in the well No. 1 of the Kuh-e-Siah in the anticline of the same name in the southeastern of Bushehr, in the Khormoj salt dome. The upper contact of the Kangan Formation with the Dashtak Formation (Aghar shale Member) from the Kazeroon Group is continuous, however, its lower contact with the Dalan Formation is separated by a disconformity (Permian-Triassic boundary) (Szabo and Kheradpir 1978) (Fig 2).

The studied wells are in the general position of the west of the field (Fig 3), the drilling depth of the well B and A is about 697 and 527 meters, respectively. From a depth of 2598 to 2774 meters, equivalent to 176 meters (well A) and a depth of 2605 to 2788 m is equivalent to 183 m (well B) belong to the Kangan Formation. Drilling cores have been produced from these wells.

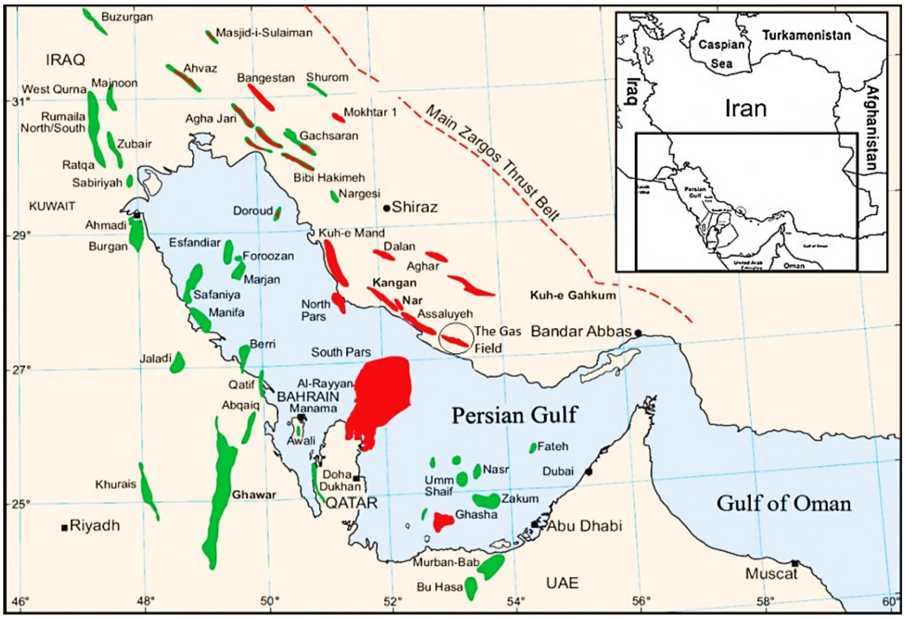

Fig 1. Geographical and geological setting of the studied gas field in the southern Zagros and northern Persian Gulf (Modified from Insalaco et al. 2006).

3. Material and methods

All studies carried out in this paper can be summarized into two sections, 1. Petrographic Analysis to investigate microfacies with the aim of investigating microfacies, effective diagenetic processes, and interpret depositional environments, and 2. To evaluate petrophysical of petrophysical logs with the aim of correlating and comparing wells A and B in terms of reservoir quality.

For this purpose, 48 microscopic thin sections from well A and 125 microscopic thin sections from well B were studied. Microscopic facies were classification using Dunham (1962), and for dolomite we used the Sibley and Gregg (1987).

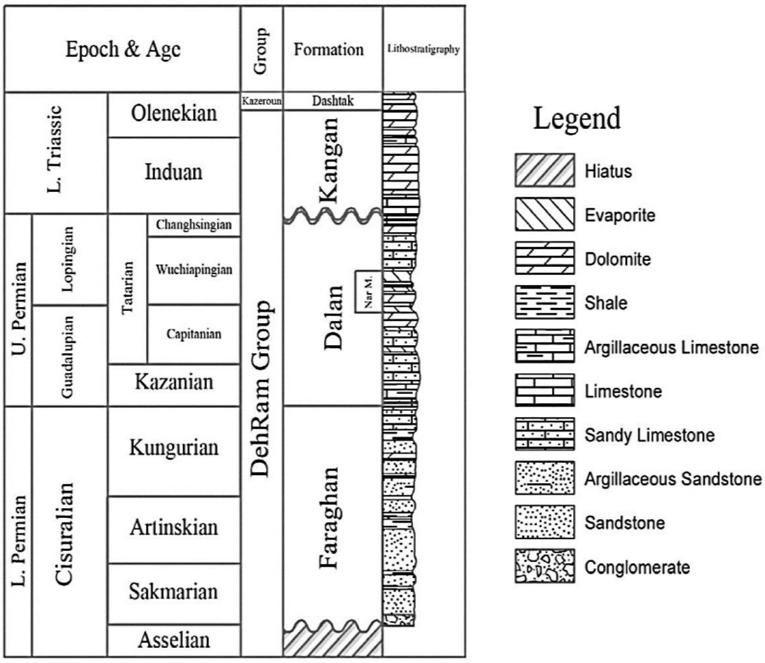

Fig 2. Lithostratigraphic column of Permian–Triassic rock units of the Zagros basin (Modified from Madani-Kivi and Zulau 2015).

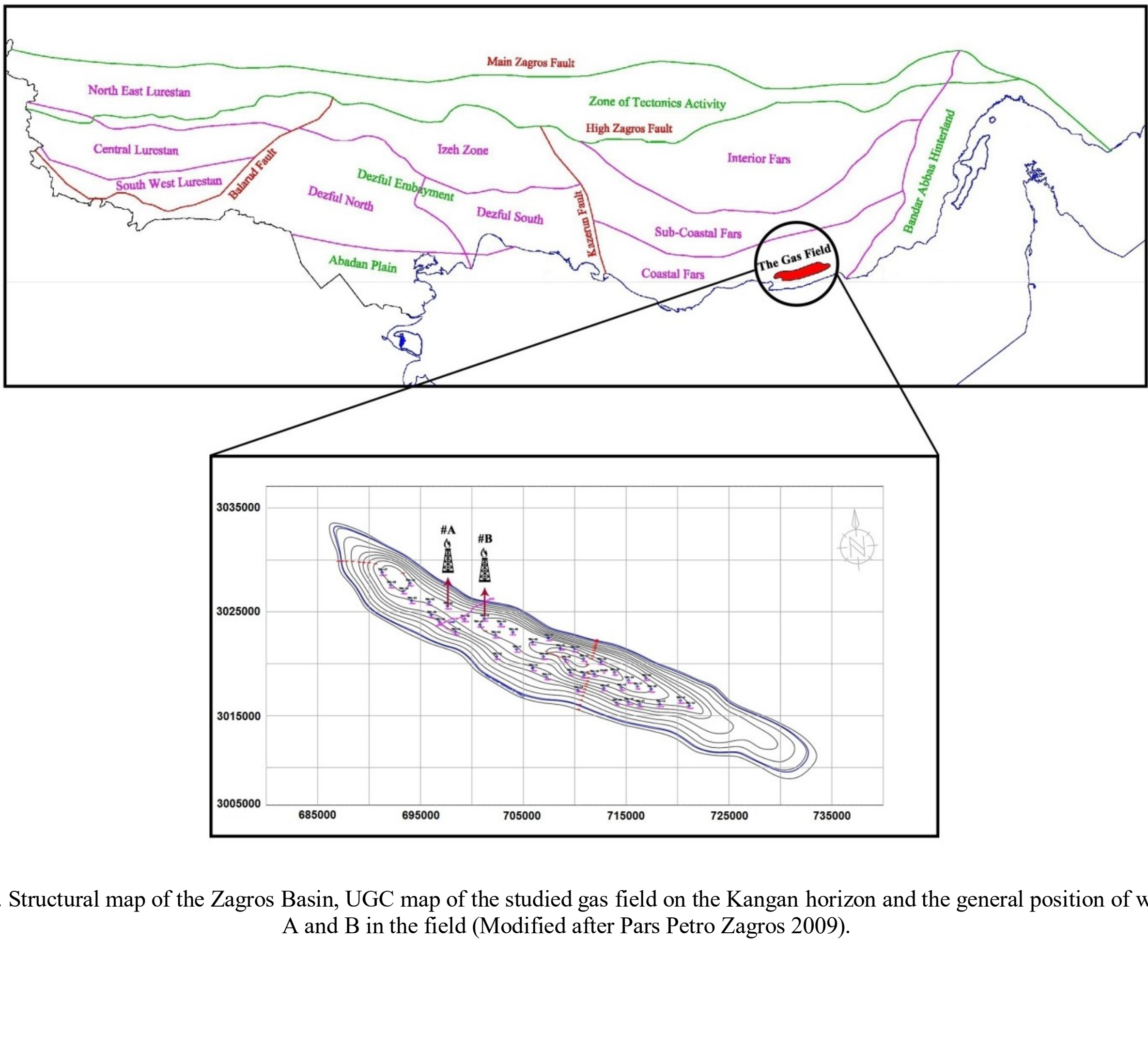

Fig 3. Structural map of the Zagros Basin, UGC map of the studied gas field on the Kangan horizon and the general position of wells A and B in the field (Modified after Pars Petro Zagros 2009).

The identification of microscopic facies was done according to the petrographic characteristics and biological assemblage, as well as comparison with the sedimentary facies, was provided by Flügel (2010).
Investigating the reservoir quality of a formation using well logs can play an important role in the quantitative and qualitative evaluation of the formation (Vafaei and Peyravi 2016). In this paper, digital raw data from the Kangan Formation well logging was used to study the quality of reservoir in two wells and its matching to petrographic studies. The raw data of these wells includes SGR, VCLGR, DT, RHOB and PHIE logs. In general, by evaluating and interpreting these logs, we can study the formation in wells in terms of reservoir quality, and decide more consciously for the parts of the formation that have better ability to produce hydrocarbon in the future plans of the field development.

4. Results and Discussion

4.1 Microfacies and depositional environment

Considering the importance of the role of sedimentary facies in controlling reservoir properties, the study of thin sections led to the identification of nine facies (a clastic lithofacies and eight carbonate microfacies) belonging to four facies belts of a homoclinal carbonate ramp including the tidal flat, lagoon, shoal and open marine.

4.1.1. Facies belt of tidal flat:

4.1.1.1. Microfacies "Ka-MF I": **Dolomitic mudstone**

This facies was observed in the form of alternative lime, argillaceous limestone, and dolomite with bright to dark gray and cream colors in the cores (Fig 4A). The thin sections of this facies contain dolomite mainly in the size of dolomicrite (average 40µ) and less in the size of dolomicrosparite (average 100µ) or an alternation of them (Figs 4B, C), with mudstone and anhydrite. Dolomite and limestone contain anhydrite needles (Fig 4D), patches and nodules in this facies (Fig 4E). Pseudo-morphs of gypsum filled with anhydrite is also visible. Non-skeletal components include pyrite in this facies. Autogenic quartz can also be found at some depths. The facies comprises large crystal dolomites in size of 400 to 700 µ at some depths scattered by 5 % to 10 % frequency. The mold of this large dolomite is mainly empty and is filled with silica cement (Fig 4F). The diagenetic processes include primary and secondary dolomitization, de-dolomitization, cementation, mainly anhydrite cement, and equant silica cement, slight dissolution (resulting in vuggy and channel porosities) and very low spread chemical compaction. The dolomite has a cloudy core and a clear rim in some depths. Porosities can be seen in the form of vuggy, channel, inter-crystalline, moldic and fracture where some of are filled with anhydrite cement and very little by covering and equant silica cement, which, as a result, reduces the porosity of this facies. This facies is comparable to the present day of Persian Gulf (Lasemi, 1995) and also with RMF 19 of Flügel (2010).

4.1.1.2. Microfacies "Ka-MF II": Laminated stromatolite boundstone

The laminated stromatolite boundstone facies occur in the laminated gray argillaceous limestone in the macroscopic study of cores (Figs 4G, H, I).
The diagenetic processes are dolomitization and de-dolomitization. Dolomite can be seen with a cloudy core and a clear rim in some depths (Fig 4J). Sibley (1980) believes that cloudy cores are formed when the dolomite making fluids are almost saturated with respect to calcite, whereas if the dolomite making fluids are under saturated with respect to calcite, bright margins are formed without inclusions. Coniglio et al. (1988) argue that the formation of dolomite crystals with the cloudy core is due to the fact that primary dolomite was probably unstable calcitic dolomites that were rapidly formed, and therefore, these dolomites contain many inclusions in their own network without any limitation.
The vuggy and inter-crystalline porosities are mostly present and in some parts are filled with anhydrite and silica cement. The laminated stromatolite boundstone facies signifies the tidal flat facies and accompanying gypsum and anhydrites suggest arid climate and deposition in the lower intertidal sub-environment (Lasemi 1995; Kavoosi et al. 2009) also this facies is comparable to RMF 22 of Flügel (2010).

4.1.1.3. Microfacies "Ka-MF III": Peloid wackestone

The peloid wackestone facies appears in the gray limestone of the available cores. It contains 30% peloid (average 0.6 mm) and anhydrite needles in thin sections (Figs 4K, L). Cementation, in especially anhydrite cement, is the most important diagenetic process in this facies. Vuggy porosity is mostly filled with anhydrite cement, and only a small amount of these porosities have been preserved. This facies is less abundance in the tidal flat facies belt and like Ka-MF2 facies has been seen in well B only and is comparable to RMF 24 of Flügel (2010).
Considering the evidence, such as the abundance of anhydrite in the form of the nodule and elongated structures, micrite background and the presence of microbial facies (stromatolites), these facies were formed in the tidal flat. The anhydrites are probably deposited in the sabkha environment, where evaporation increased and evaporate minerals formed, the amount of calcium reduces and the ratio of magnesium to calcium increases, as a result, anhydrite are formed in the environment (Butler et al. 1982; Warren 2000). Due to the mass extinction at the time of Permian-triassic (Kennard and James 1986), as well as due to the high salinity of this facies belt, microbial facies can be observed in the Kangan Formation. In general, the porosities of this facies belt are often filled with anhydrite cement. The Kangan Formation has some evaporitic interbeds.

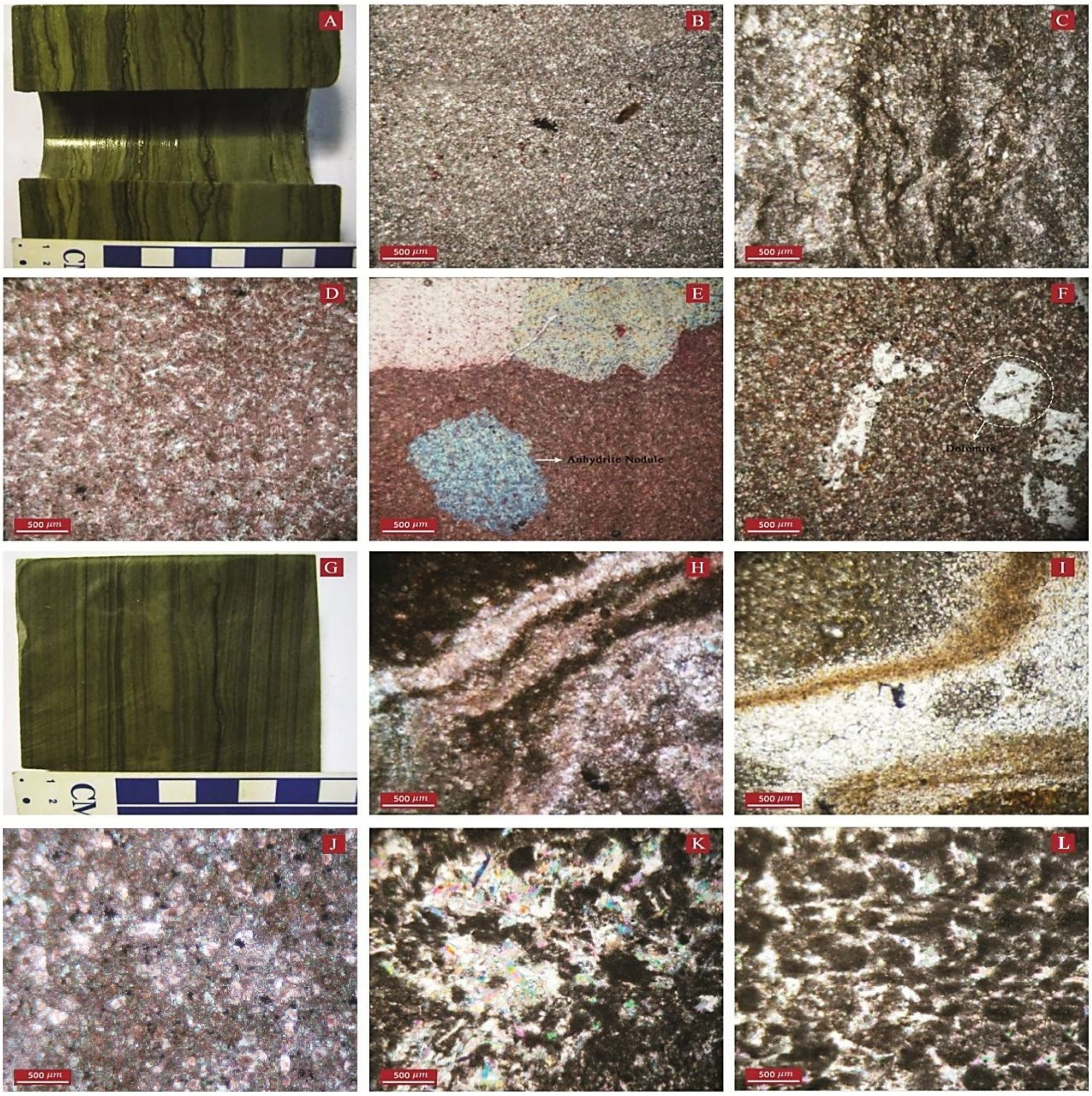

Fig 4.Well "B", A. the alternation of argillic limestone with dolomite (light grey), depth: 2652.58- 2652.67m. B. Dolomudstone facies, dolomitization, depth: 2672.25m. C. Dolomudstone facies, the alternation of dolomicrite and dolosparite, depth: 2652.62m. D. Mudstone facies with anhydrite needles, depth: 2679.60m. E. Mudstone facies with anhydrite nodule, depth: 2678.1m. F. Dolomicrosparite facies with dolomite crystals and autogenic quartz, depth: 2668.85m. G. Macroscopic view of stromatolite boundstone (grey), depth: 2762m. H. Boundstone texture, remark: minor dolomitization, depth: 2761m. I. Boundstone texture, remark: dolomitization, depth: 2755m. J. Dolomitic mudstone, remark: the some dolomites have a cloudy core and clear rim, depth: 2757m. K. Peloid wackestone facies, remark: anhydrite cement, depth: 2682.90m. L. Peloidal wackestone facies, remark: anhydrite cement, depth: 2683m.

So, the source of evaporate is attributed to the Kangan evaporates and associated brine waters as connate waters. Therefore, this facies belt does not have such a desirable reservoir quality.

4.1.2. Facies belt of lagoon:

4.1.2.1. Lithofacies "Ka-LF IV": Claystone

This facies seen as dark gray claystone (shale) in the macroscopic view (Fig 5A). In the microscopic view, it is a muddy facies, which has pyrite (Fig 5B) Less than 5 percent of pelecypod fossils were observed which their molds were filled with silica cement (Fig 5C). This facies belongs to a lagoon environment and probably representing less water circulation (reduction condition) (Insalaco et al. 2006). The significant quantities of organic matter were found in this shale, suggesting the entry of debris into the basin (Fig 5D). In terms of reservoir quality, this facies lacked reservoir potential and can even be considered as cap-rock for the lower units.

4.1.2.2. Microfacies "Ka-MF V": Bioclast wackestone / packstone

The facies appear in the dark gray color in the microscopic observations (Fig 5E), and in the

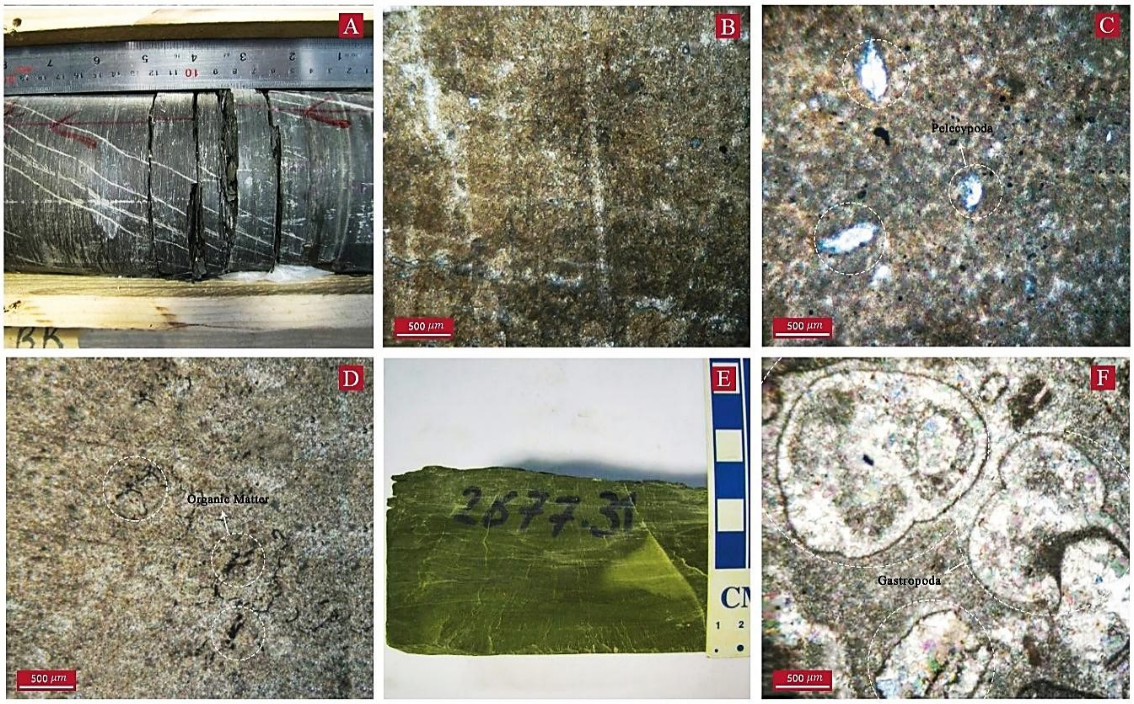

Fig 5.Well "B", A. Dark shale facies (core) and B. Claystone (thin section), depth: 2673.80m. C. Mudstone facies, remark: the pelecypods filled with silica cement, depth: 2677.31m. D. Mudstone facies, remark: organic matter, depth: 2674.75m. E. Macroscopic view of grey marly limestone, depth: 2677.31m. F. Packstone facies with gastropod fossil, depth: 2677.55m.

microscopic study, is a wackestone with 10% scattered skeletal fragments and a little peloid with a mean size of 0.5 mm and rounded intraclast (about 5%). The skeletal components of this facies include benthic bivalves and gastropods (Fig 5F). The skeletal grains such as gastropods and benthic bivalves together peloids and intraclast occur in the backshoal of lagoon. Intrclast and peloid suggest storm activity and/or washover sediments, (Flügel 1982; Lasemi 1995; Tucker and Wright 1990).

The main diagenetic processes include cementation (including first-generation fibrous cement and equant, anhydrite, silica, and syntaxial cement), dolomitization, dissolution (which lead to the generation of vuggy and channel porosities), micritization and physical and chemical compactions. The porosity types observed in this facies include moldic, intraparticle, vuggy, channel and shelter, which some of them are filled with equant and anhydrite cements. And also this facies is comparable to RMF 20 of Flügel. (2010).

4.1.3. Facies belt of shoal:

4.1.3.1. Microfacies "Ka-MF VI": Peloid grainstone

This facies has a bright grey color limestone in the macroscopic view (Fig 6A). It comprises more than 30% peloid with a mean size of 0.4 mm, 10% ooid with a mean size of 1 mm and rounded intraclast (Figs 6B, C). Non-skeletal grains are accompanied by 10 percent skeletal grains including gastropods and bivalves.

The diagenetic processes affected the facies include micritization, dissolution, cementation (including first-generation bladed cement, dolomite and equant), dolomitization, neomorphism (Fig 6D), and physical and chemical compactions. Most of the allochems are affected by micritization and, in some cases, due to dissolution; the moldic porosity is also formed. This facies has also been partially subjected to an anhydritization, which has reduced reservoir properties in parts of this facies. This facies is comparable to RMF 28 of Flügel (2010).

4.1.3.2. Microfacies "Ka-MF VII": Ooid grainstone

The loud grainstone is a porous and represents cream color with a large amount of vuggy porosity (molds of ooids) in the macroscopic view (Fig 6E). It includes more than 50% sorted ooid with a mean size of 0.7 - 1 mm (Fig 6F, G). The high sorting and roundness of the ooids in a sparitic matrix indicates the high energy level and constant wave and current activity in the depositional environment (Tucker 1993; Lasemi 1995). Some peloid, intraclast, and bioclast particles (less than 10%) are present at some depths. The diagenetic processes affected this facies include cementation (including fibrous-to-bladed cements, equant, siliceous and very little dolomite cements, as well as drusy cement in the form of porosity filler) (Fig 6H), (which led to the formation of moldic, vuggy and channel porosities), and less physical and chemical compaction (which led to the deformation and fracture of the ooids), micritization and neomorphic alteration. The porosity types include moldic, intraparticle, vuggy, channel,

Fig 6. A. Well "A", Peloidal grey limestone (core), depth: 2643.65m. B. Well "A", Peloid grainstone facies, depth: 2643.60m. C. Well "A", Peloid grainstone facies, peloids filled with dolomite cement, depth: 2645.12m. D. Well "A", Peloid grainstone facies, major neomorphism of peloids, depth: 2669.65m. E. Well "A", macroscopic view from porous lime, depth: 2643.12m. F. Well "B", Ooid grainstone facies, remark: composite ooid, depth: 2644.40m. G. Well "B", Ooid grainstone facies, remark: equant cement partly filled interparticle porosity, depth: 2645.40m. H. Well "B", Ooid grainstone facies, remark: drusy cement, depth: 2644m. I. well "B", Ooid grainstone facies, remark: oomolds filled with anhydrite cement, depth: 2665.95m. J. Well "B", Ooid grainstone facies, oomolds, depth: 2644m. K. Well "A", Macroscopic view from porous grey lime (core), remark: stylolite, depth: 2647.12 - 2647.35m. L. well "A", Ooid bioclast grainstone facies, neomorphism of ooid, remarks: the dissolution of bivalve and filled with equant cement, depth: 2647.20m. M. Well "B", Ooid bioclast grainstone facies, remark: the ooid with bivalve nucleus, depth: 2664.65m. N. Well "A", Ooid bioclast grainstone facies, remark: fibrous-to-bladed isopachous cement, depth: 2646.55m. O. Well "B", Ooid bioclast grainstone facies, remarks: fibrous cement on bivalve fossil, equant cement with high inclusion, depth: 2671m.

interparticle and the porosity resulting from the fracture, which is mostly empty, and a few of them are filled with equant calcite, anhydrite, and silica cement and very less with dolomite cement.

The most important porosity is moldic porosity, which formed by the dissolution of the ooids (Fig 6I, J). This facies is comparable to RMF 29 of Flügel (2010). Also it is notable that this facies has a higher porosity, permeability and reservoir quality than other facies (Nowbahar et al. 2015).

4.1.3.3. Microfacies "Ka-MF VIII": Bioclastic ooid grainstone

This facies is a porous gray limestone with a large amount of moldic porosity and stylolites in the macroscopic view (Fig 6K) more than 30% of well-sorted ooids with a relative size of 1-1.5 mm (Fig 6L), and less than 20% peloid particles (less than 1 mm) together with coarse intraclasts with a size of more than 2 mm in thin section. This facies with 20% of large bivalves (Fig 6M) and the algal mat can be separated from the previous facies. It should be noted at some depths, the facies is largely affected by neomorphic alteration and at some parts the algal mat are found in the form of large particles with irregular and completely neomorphic margins. At some depths, the size of these fragments, as well as large bivalves, greatly increase and it form the bioclast ooid grainstone. The high sorting and roundness of ooids in the sparitic cement show the high energy level of the environment.

Diagenetic processes affected this facies include various types of cementation, including fibrous-to-bladed cement (Fig 6N,O), first-generation and second-generation equant cements (Fig 7A) as well as anhydrite, drusy, covering and a small amount of dolomite and silica cements in the form of porosity fillers (Fig 7B,C), dissolution (led to the formation of moldic, vuggy and channel porosities) (Fig 7D), neomorphic alteration, physical (led to the deformation and breaking of the ooids and bivalve) and chemical compaction (stylolite) (Fig 7E), micritization, dolomitization and dedolomitization.

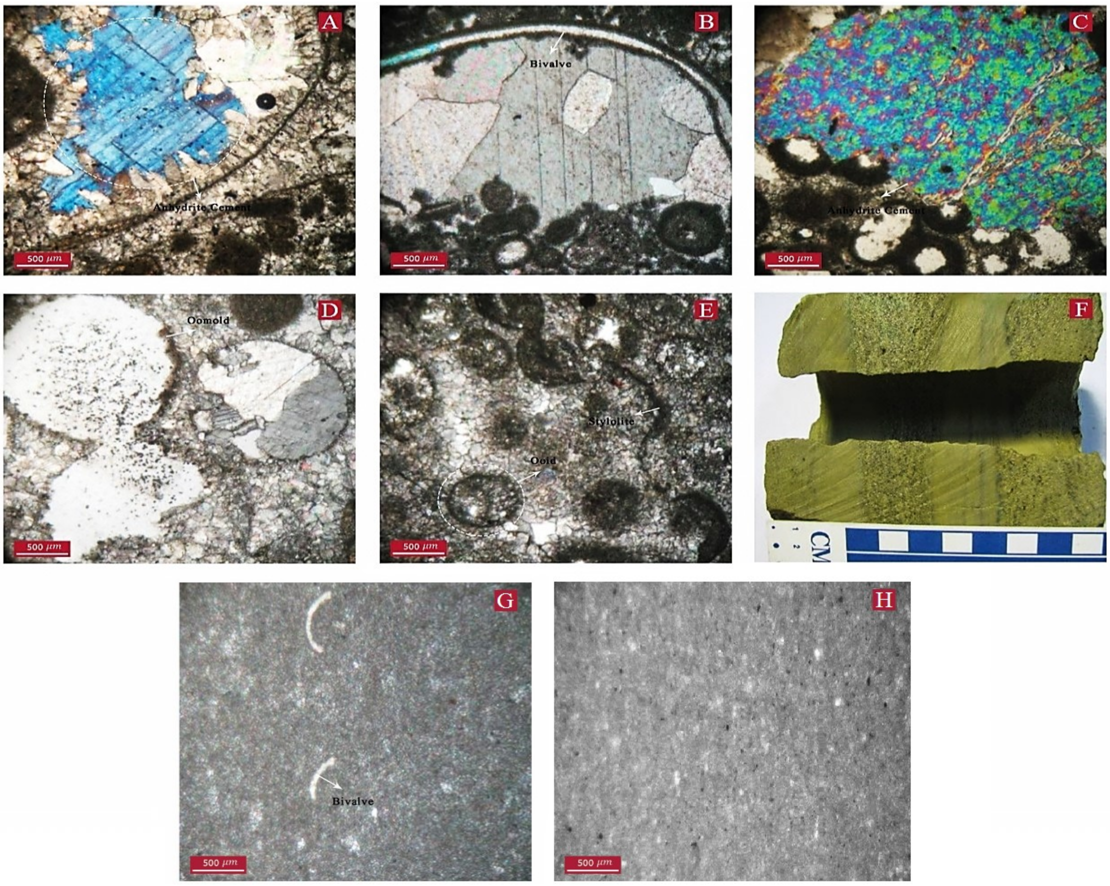

Fig 7. A. Well "A", Ooid bioclast grainstone facies, remark: the growth of bladed cements as marine and burial cement (anhydrite cement) on the interior margin of bivalve fossil, depth: 2647.80m. B. Well "B", Ooid bioclast grainstone facies, remark: benthic bivalve; Shelter porosity, geopetal fabric, depth: 2667.10m. C. Well "A", Ooid bioclast grainstone facies, remark: vuggy porosity filled with anhydrite cement, depth: 2652.25m. D. Well, "A", Ooid bioclast grainstone facies, remark: oomold; unstable mineralogical composite (HMC or aragonite) of ooids, depth: 2647.20m. E. Well "B", Ooid bioclast grainstone facies, remark: the stylolitization, depth: 2642m. F. Well "B", macroscopic view from the alternation of porous lime of shoal and non-porous lime of open marine, depth: 2645.35- 2645.42m G. Well "B", Mudstone facies, remark: bivalve/claria fossil, depth: 2645.40m. H. Well "B", Mudstone facies, depth: 2652.65m.

Dissolution is the main process that created porosity in the facies. The dissolution process has mainly operated in fabric selective manner leading to the formation of moldic porosity resulting from the dissolution of the ooids, bivalves, and intraclasts. In some cases, this process is non-fabric selective and has created vuggy and channel porosity. The porosities are mainly empty and, in some cases, partly filled with calcite, anhydritic and dolomitic cements.

The channel porosity connects the moldic porosity and increases permeability in some cases. Interparticle porosity can also be observed, which some of them are filled with equant and anhydrite cement. The skeletal and non-skeletal grains together with lack of micrites suggest deposition in the inlet channels that cut the carbonate shoals/barrier (Lasemi 1995; Kavoosi 2014). This facies is comparable to RMF 30 of Flügel (2010). Similar to the previous facies, this facies also has a good reservoir quality because of high porosity and permeability.

The spread of carbonate facies of shoal is an indicator of the ramp environment (Elrick and Read 1991). This facies belt is considered as the main reservoir of the Kangan Formation in the study area due to high reservoir quality. The size of the particles is another important point in this facies belt; the components in the seaward include the coarse pieces of skeletal particles and intraclasts, while the leeward facies is mainly composed of peloids and fine ooids together with some small skeletal particles.

4.1.4. Facies belt of open marine

4.1.4.1. Microfacies "Ka-MF IX": Mudstone / Fossiliferous Mudstone

This facies is a non-porous olive limestone in the core (Fig 7F), and in thin section, is a mudstone with a dark matrix containing 5% bivalve shell in some depths (Fig 7G, H). The presence of mud indicates a calm and low energy environment. Also, the absence of structures and bioclasts related to the internal ramp and thinning of the shells (bivalves), mainly related to deep water with a low temperature, shows the sedimentation in the deeper parts of the basin, such as mid-ramp.

Dolomitization and cementation are diagenetic processes affected this facies. This facies lacks does not have desirable reservoir quality and is comparable to RMF16 of Flügel (2010). Generally, in the studied formation, the nine facies types were distinguished. Theses facies and their inferred depositional model are shown in Fig 8.

4.2. Types of porosity and the relationship between porosity and permeability

In general, the porosity in reservoir limestone (the oolithic facies of the shoal facies belt) is mainly of moldic, vuggy and isolate porosities, which are highly porous with low permeability (Fig 9A1, A2). The macroscopic studies of the cores also show that the pores in the limestones are mainly moldic and isolate porosity (Fig 9A1, A2). It worth to mention that at some intervals, the pores in the limestones are observed as both isolate and connected types. It should be mentioned that the moldic porosity is associated with greater dissolution such as channel porosity (Fig 9B1, B2). In Figure 9-B1 and B2 the moldic porosity (oomolds) is formed by dissolution, and in Figure 9C1 and C2, the moldic porosity (oomolds) is related with to the fracturing, which slightly increases the permeability. Accordingly, the porosity and permeability values measured by the cores analysis (by the ICOFC), it seems that with increasing burial depth, while the facies represent high porosity but the permeability is low, On the other hand on some intervals that both porosity and permeability are high, the porosity is mainly connected. In Figure 9D1 and D2 also shows that the moldic porosity related to narrow pores.

In the dolomudstone facies, due to the intercrystalline porosity and their relationship to gather with the small pores in matrix, the value of permeability increased significantly. Although, at some depths, these small pores are filled with anhydrite cement the amount of permeability reduces. By increasing the amount of anhydrite cement, there is a further decrease in the porosity and permeability measurements. In general, the value of permeability in dolomites is greater than limestones, which is due to the connection of pores together (high effective porosity), but in limestones, the porosity is mostly isolated type therefore they have less permeability. In limestone intervals due to the existence of the channel and fracture porosity they have reservoir potential. In order to investigate the porosity and permeability values of different facies and their relationship with facies, the measured value of porosity and permeability of cores were plotted (Fig 10).

4.3. Diagenetic processes

According to the studies on the diagenesis and the identification of various diagenetic processes, these processes are divided into three categories: 1. those increased the reservoir quality, 2. those decreased the reservoir quality and 3. those without any effect on the reservoir quality. Diagenetic processes affected the reservoir quality of the Kangan Formation include mechanical and chemical compactions, dissolution, dolomitization, cementation, fracturing and neomorphism. Among them, compaction and different cement types can be considered as processes that decreased the reservoir quality. Meanwhile, dissolution, dolomitization and fracturing processes have increased the reservoir quality. Due to limited spreading of pyritization and silicification processes, they have no effect on the reservoir quality (Fig 11). In general, in this research, one of the most important processes affecting reservoir quality is anhydrite cement. It can be seen that the development of anhydrite cement with various textures has controlled the reservoir quality in

three ways: primary sedimentary texture, the presence of sulfate-rich saline fluids and dissolution and fracturing diagenetic processes.
The porosity in carbonate rocks is divided into two groups: primary and secondary porosity. Primary porosity exists initially among sedimentary particles and secondary porosity occurs at any time after the final sedimentation (Choquette and Pray 1970).
In general, porosity types observed in microscopic thin sections include interparticle, intraparticle, moldic, intercrystalline, fracture, vuggy, and channel porosities which have an important role in the reservoir quality of the formation. According to Choquette and Pray (1970), interparticle, intraparticle, intercrystalline, moldic and fenestral porosities are fabric selective and porosity from fracturing, vuggy and channel porosities are non-fabric selective. All observed porosity types can be put in these two groups.

4.4. Petrophysical assessment of reservoir quality of the Kangan Formation in the studied field

The lithology type, water saturation and total porosity are of the most important petrophysical parameters of a reservoir (Kiakojury et al. 2018). These parameters can be expanded in the studied wells qualitatively, in addition to quantitative relationships. In general, three mentioned parameters have a direct relationship to each other, so that if the lithology type of the reservoir is fine and compacted (high shale volume and low porosity) and saturation of water is high, then the total porosity decreases and the reservoir does not have a suitable quality.
According to previous studies, the Kangan Formation is classified into four zones in terms of reservoir potential: Ka-1, Ka-2, Ka-3, Ka-4 zones, among which the first and the fourth zones are classified into two sub-zones Ka-1b and Ka-1a, Ka-4b and Ka-4a. This zonation is based on the lithological characteristics and depositional environments of the Kangan Formation in drilled wells of different fields in the Zagros fold-thrust belt. Therefore, with a general review of the reservoir properties of the Kangan Formation zones, it is concluded that the Ka-2 zone is the best producing zone and the Ka-4 zone is the lowest zone in terms of production. This fact can be proved according to lithological characteristics, depositional environment, and their petrophysical parameters. The second zone with average water saturation and total porosity of 43.3% and 10.7% respectively is one of the best producing zones, as only 13% of its total lithology has the total porosity less than 2%. However, the first sub-zone of the fourth zone with a mean total porosity of less than 0.8% and water saturation of about 89.7% is very poor in terms of reservoir quality due to shale and clay layers in the lithology context.

4.5. Reservoir quality assessment of studied Wells based on the well logs

Since cost reduction and speed of the work are very important in the study of hydrocarbon fields, and usually a few wells in each field, have cores, therefore, for more detailed and advanced studies, petrophysical logs are used even for zonation. The best advantage of the petrophysical logs over outcrops is the availability of continuous and more comprehensive information from relatively thick sequences (Ehrenberg et al. 2008).
In this study, logs were interpreted based on petrophysical properties and was correlated with lithology in wells A and B. After that, high-quality reservoir horizons were determined and two RQ-1 and RQ-2 quality types were introduced for each well. The RQ-1 quality type contains intermediate layers with low thickness and high reservoir quality, but they do not have high storage volume due to limited distribution.
In contrast, that part of the formation which has RQ-2 quality, in fact, contains thick layers with high reservoir quality, and high storage capacity because of their extensive distribution.
Major lithologies of the formation in the cores are limestone (grainstone) and dolomite (dolomicrosparite) with inter-layers of shale and anhydrite, which causes different physical properties in this reservoir. The passage time of a dense lithography unit is much lower than that of a porous unit, resulting in the trend of the sonic log peak toward lower values, and vice versa (Schlumberger 1989). Another noteworthy point is the change in the energy level of the electrons, which depends on the total density of the matter (the type of lithology) (Asquith and Krygowski 2004). Its explanation is very simple on the well logs, if a lithology unit is more compacted than a porous unit, its density is more as well, and in the graph, the peak of the density log tends to the maximum number (Asquith and Gibosn 1982).
The effective porosity is one of the most important reservoir parameters, which is essential for determining reservoir horizons. In the Kangan Formation, due to the lithological diversity, especially in terms of reservoir potential, the peaks of effective porosity logs are greatly important for their accuracy, and as the peak increases, the effective porosity of the formation will be more. The shale; for example, is a rock unit with high micro-porosity, but due to the lack of connection between the pores, it has a very low effective porosity (Schlumberger 2007). It should be noted that by integrating this log with other logs, the potential of various lithology of a formation to be a reservoir can be evaluated. Also, the number of radioactive elements in a substance can affect radioactivity analysis. The lithological units in which their mineralogical structure contains radioactive elements show higher peaks of gamma ray (Daarling 2005). Accordingly, the volume of the shale is very helpful in the interpretation of the quality of reservoir zones (high quality) in the wells.

Therefore, all of these parameters are represented in the graphs below the columns of the lithological chart, sonic log, density, effective porosity and gamma-ray logs for a comprehensive study with the aim of comparing the reservoir quality of the two wells (Fig 12).

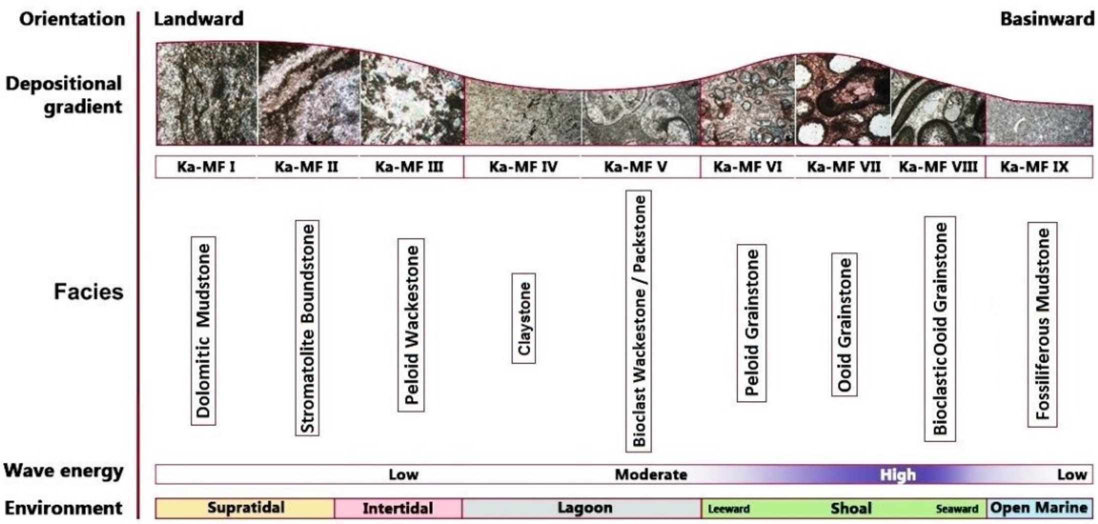

Fig 8. Schematic Profile of Kangan Formation depositional environments with distribution of facies in different parts of the study area.

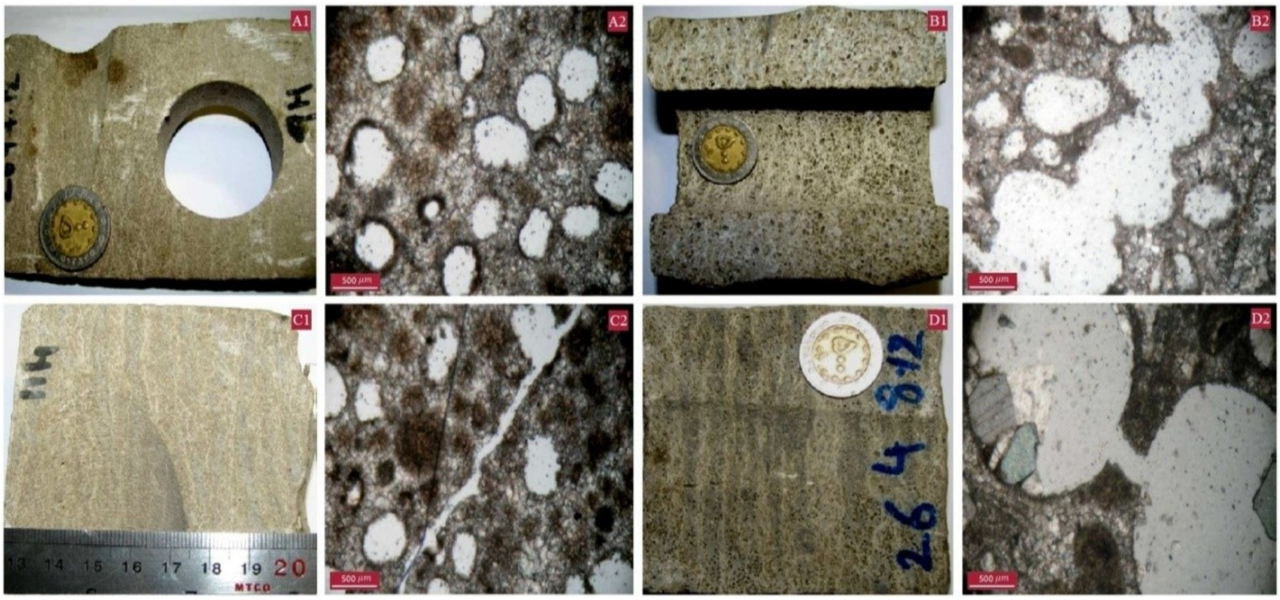

Fig 9. A1, A2. well "A", the macroscopic and microscopic view of grainstone (oosparite), remark: oomold; unstable mineralogical composite (HMC or aragonite) of ooids, Shoal facies, depth: 2647.10m, porosity: 24%, permeability: 0.74 md (the porosity is high and permeability is low). B1, B2. well "A", the macroscopic and microscopic view of grainstone (oosparite), remark: moldic porosity; unstable mineralogical composite (HMC or aragonite) of ooids and peloids, depth: 2647.80m, porosity: 22%, permeability: 0.89 md. C1, C2. well "A", the macroscopic and microscopic view of grainstone (oosparite), remark: oomold; unstable mineralogical composite (HMC or aragonite) of ooids, the fracture porosity causes the relation between the ooids and thus has been increased permeability, shoal facies, depth: 2647.60m, porosity: 27%, permeability: 4.16 md. D1, D2. well "A", the macroscopic and microscopic view of grainstone (oosparite), remark: oomold; unstable mineralogical composite (HMC or aragonite) of ooids, shoal facies, depth: 2648.30m, porosity: 20.7%, permeability: 0.99 md.

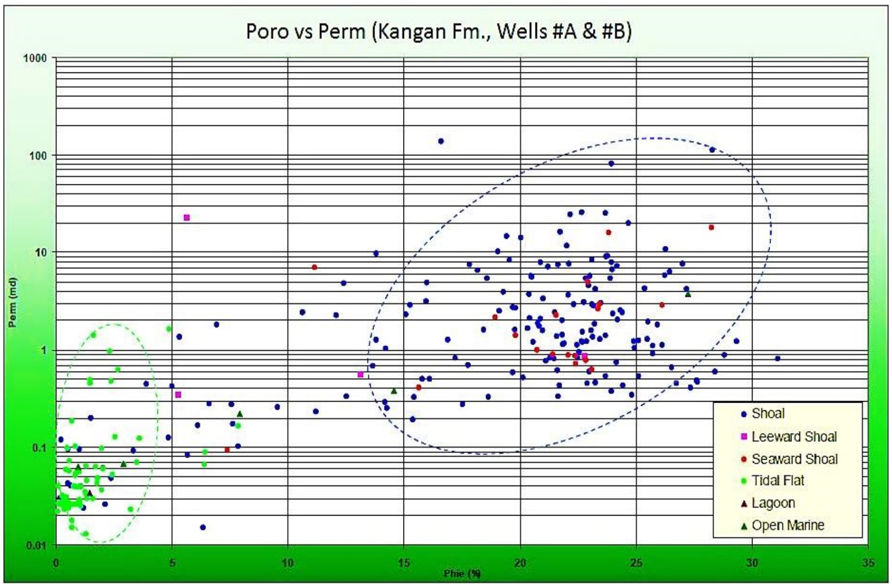

Fig 10. The values of porosity versus permeability in sections of the cores taken of the Kangan Formation in wells of No.A and No.B, in the blue range, the shoal facies has the highest porosity-permeability and the best reservoir quality.

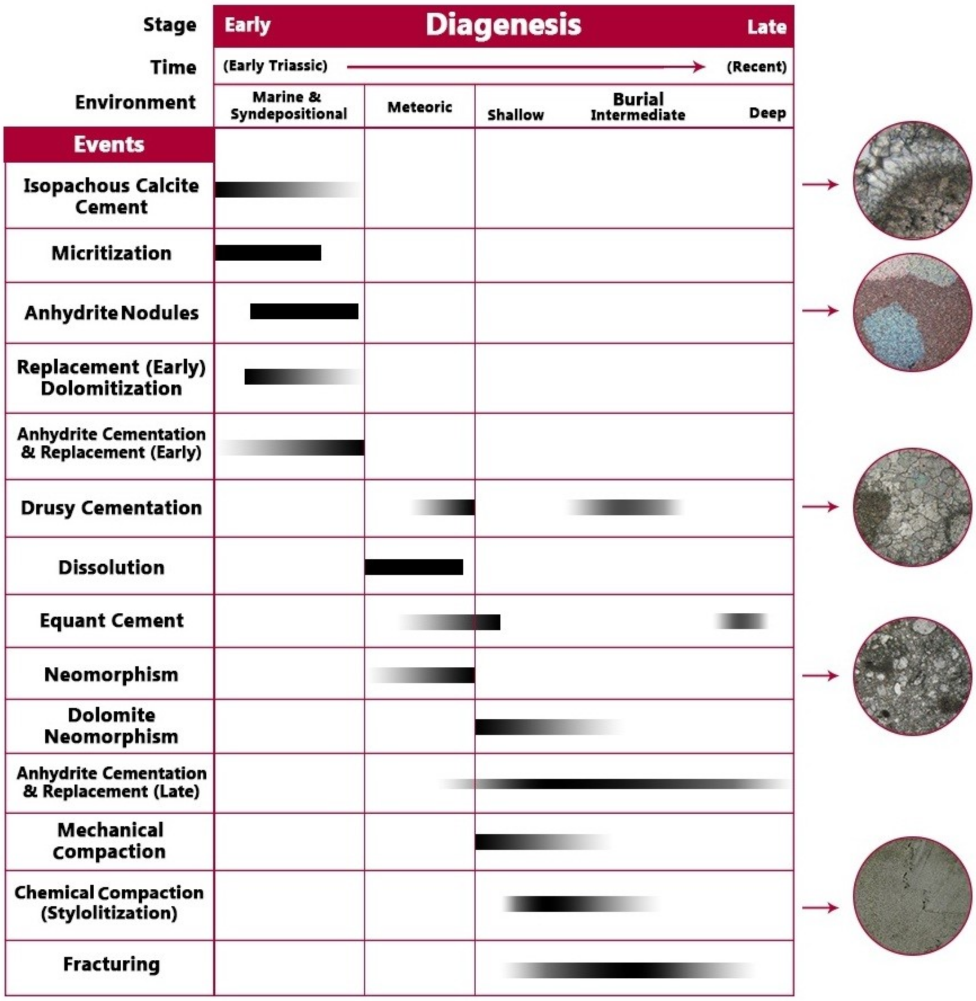

Fig 11. Generalized diagenetic sequence of the Kangan Formation. Paragenetic sequence and diagenetic environment are clear.

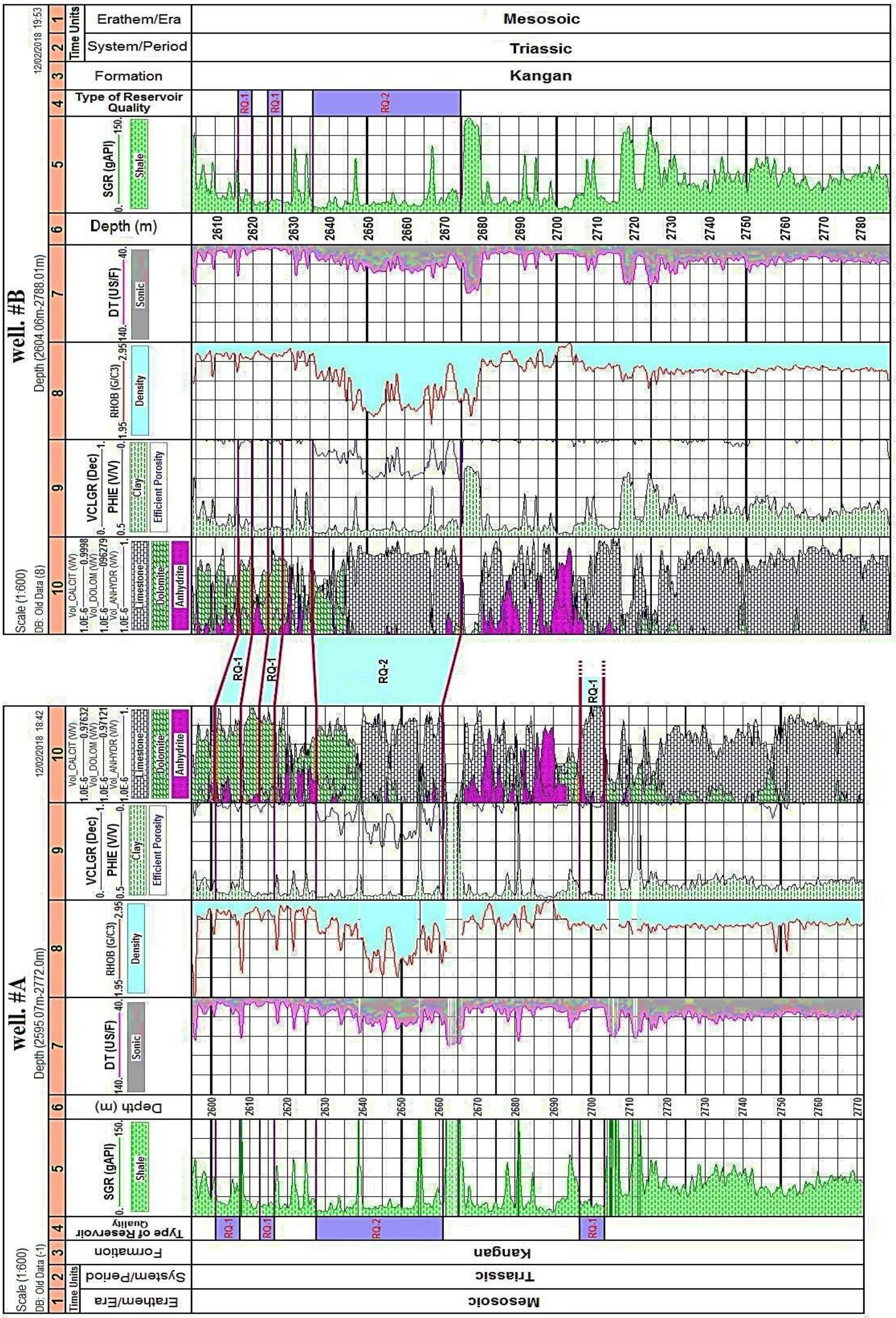

Fig 12. The lithological chart, petrophysical logs, the determination of types of reservoir quality and the comparison them in different depths based on numerical data available from wells "A" and "B".

4.5.1. Types of reservoir quality
By combining the information obtained from the petrography and petrophysical logs of two wells A and B, layers with good reservoir quality were identified and studied. These layers will be described and explained briefly in the following.

4.5.1.1. Well "A"
Regarding changes in the peaks of the well logs, three reservoir horizons with RQ-1 and RQ-2 quality types were identified in this well. All of these horizons were identified based on well logs in the first step, and its accuracy was then determined by correlating with petrographic studies. Based on the lithology column (the total volume of lithology changes in the formation), two RQ-1 horizons are distinguished at the depth of 2601 to 2607 and 2612 to 2616 meters. The lithology of these two fairly thin horizons is mainly dolomite with anhydrite and shale inter-layers (according to the SGR log). The dolomudstone facies was deposited on the supratidal environment. Petrophysical behavior of logs show that effective porosity log with a value of more than zero and a low percentage of shale volume (0.2% average) have made these horizons as suitable reservoirs, but the peak increase of the density log shows the presence of anhydrite which acts as a separator of these two horizons, and also causes decreasing reservoir quality. The third horizon of this quality type is at a depth of 2696 to 2704 meters comprises limestone and anhydrite inter-layers. The petrophysical behavior of the logs is approximately the same as the two mentioned horizons and despite the relatively good quality of these horizons, they are not high producing reservoir layers due to their small thickness and lateral limited distribution.

At the depth of 2662 to 2627 meters, the peaks of the effective porosity log have a value of 0.25, RHOB log tends to be minimal, and the VCL and SGR logs are in the minimum state. According to the stratigraphic column, at this depth the lithology is dolomite (from a depth of 2627-2638 meters) and limestone (from a depth of 2639-2662 meters), with very thin inter-layers of shale and anhydrite. Based on the petrographic studies, the dominant microfacies in this well can be considered as the grainstone facies of the shoal environment. The grainstone facies has the best reservoir quality because of its suitable fabric, as described in detail in the petrography. This section of the well has RQ-2 quality type and because of its high thickness, it can have high hydrocarbon storage.

4.5.1.2. Well "B"
In this well, a reservoir layer with RQ-2 quality type and two reservoir layers with RQ-1 quality type was distinguished based on the changes in petrophysical properties of well logs like well A.

According to the lithology column, at depths of 2616 to 2620 and 2624 to 2628 meters, the dominant lithology is dolomite with inter-layers of limestone belonging to the sedimentary facies of the tidal flat zone. Anhydrite inter-layer is the most important factor in separating these two thin reservoir horizons (RQ-1) in this well too. The reservoir properties of this well are quite similar to well A. This similarity is more obvious in the depth of 2635 to 2675 meters with the same lithology of thick RQ-2 reservoir layer like well A. This depth stands for the thick high-quality RQ-2 layer, which contains high storage potential regarding to the peaks of the well logs especially the PHIE log.

Finally, it should be noted that the overall purpose of this study was to have a more accurate investigation of the reservoir horizons of the Kangan Formation, particularly in the studied field. Because the basis of reservoir quality studies in the past was more based on lithological changes, effective diagenetic processes, and depositional environments of the Kangan Formation, and was even extended to the whole of the Formation. Therefore, in this paper, have been tried to accurately outline the horizons of this formation, which has a reservoir quality and high hydrocarbon storage capacity by studying well data and integrating them with petrographic studies. However, zones of the Kangan Formation may differ in terms of reservoir quality in wells of a field due to facies changes. Therefore, according to this study, it is recommended to study and analyze the wells separately in order to identify the reservoir layers of the formation.

5. Conclusion
Kangan Formation in the gas field was deposited in a shallow carbonate ramp. Petrographic studies revealed 9 microfacies including dolomitic mudstone, stromatolite boundstone, peloid wackestone, claystone, bioclast wackestone/packstone, peloid grainstone, ooid grainstone, bioclast ooid grainstone, fossiliferous mudstone.

The RQ-1 quality type consists of inter-layers with a low thickness which has high reservoir quality but do not have a high storage potential due to their limited distribution. But the quality type of RQ-2 consists of thicker layers that have high storage potential due to their lateral distribution and high reservoir quality.

Generally, the information obtained from petrography and the depositional environment is complementary to petrophysical data. Therefore, there should be a combination of a qualitative and quantitative study (software) for accurate research.

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