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Diagenetic Facies Study of Chang 8 Reservoir in Triassic Yanchang Formation in Jiangjiachuan Area of Ordos Basin

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Abstract

On the basis of well logging and logging data, combined with the analysis of thin section and SEM. The diagenesis of Chang 8 reservoir in Triassic Yanchang Formation in Fuxian Jiangjiachuan area of Ordos basin were analyzed. Four diagenetic facies were divided:

a) Chlorite membrane cementation-residual intergranular pores + feldspar corrosion facies

b) Chlorite, illite cementation-residual intergranular pores + feldspar corrosion facies

c) illite cementation-feldspar corrosion facies

d) Carbonate cement phase

According to the study results of diagenetic facies, combined with production test data statistical results, the capacity of different types of diagenetic facies was analyzed.

Keywords: Yanchang Formation; Chang 8 reservoir; Diagenesis; Diagenetic faces; Ordos Basin

Introduction

The diagenetic facies can be used as genetic markers of reservoir undergoing multi-type and multi-stage digenesis transformation, and then through the favorable diagenetic facies to screen out effective reservoirs, it has attracted more and more scholars' attention. Previous studies on the Chang 8 tight reservoir in the Jiangjiachuan area of the Ordos Basin mainly focused on reservoir micro-pore structure, mode of movable fluid occurrence and reservoir evaluation, but few studies on quantitative division and description of characteristic differences. Based on the knowledge of oil and gas reservoir geology and sedimentology, this paper studies diagenesis by means of casting thin section, cathode luminescence, grain image, X-ray diffraction and scanning electron microscope, and quantitatively identifies and classifies diagenetic facies, elaborates the characteristics of different diagenetic facies, and analyzes the production capacity of different diagenetic facies.

The Jiangjiachuan area is in the northeast of Zhiluo Town in Fuxian County, Shaanxi Province (Figure 1), about 30km west of Fuxian County. Oil and gas exploration and development was begun in study area from 2010. The tight oil was discovered in Triassic Yanchang Formation that developed delta sedimentary. The micro-facies are delta front sub-facies, forming sandstone reservoirs with wide distribution, good continuity, developed micro pores, complex diagenesis and difficult to development. The Jiangjiachuan area is located in the northeast of Zhiluo Town in Fuxian County, Shaanxi Province, about 30km west of Fuxian County. Oil and gas exploration and development was begun in study area from 2010. The tight oil was discovered in Triassic Yanchang Formation that developed delta sedimentary. The micro-facies are delta front sub-facies, forming sandstone reservoirs with wide distribution, good continuity, developed micro pores, complex diagenesis and difficult to development.

Diagenesis Characteristics

After the formation of sedimentary rocks, due to the strong influence of diagenesis, vertical zonation is determined, which makes the reservoir composition, structure and reservoir performance change greatly. Therefore, it is necessary to analyze the formation of tight reservoir through diagenesis by mechanism and evolution process.

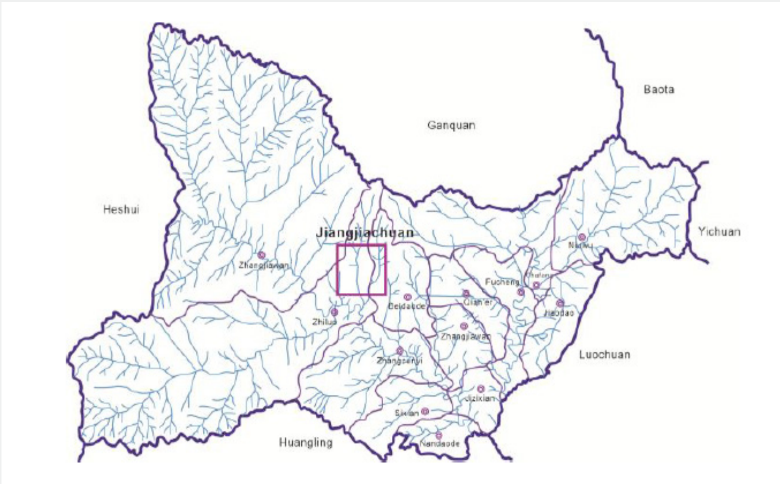

Figure 1: Geographical Location Map of the Study Area.

Compaction

The mechanical compaction of Chang 8 reservoir is mainly characterized by: the clastic grains are arranged and packed tightly in directional to semi-directionally, the plastic grains such as mica are compressed and deformed or produced in a pseudo hetero-base state; the inter-grain contact mode changes from point contact to point-to-line contact or line contact, the rigid clastic minerals such as quartz and feldspar are fractured or even crushed (Figure 2a & 2b). Under the action of overburden pressure, the water in the formation was discharged, the rock grains are closely arranged, the pores of the reservoir were reduced, and the properties are deteriorated [1] When the overlying formation pressure (or structural pressure) exceeds the hydrostatic pressure, the grain contact undergoes lattice deformation and corrosion locally, and pressure dissolution occurs to generate a large amount of silica, and the reactant is enriched at the edge of the grain to form a secondary addition. When the reactants are enriched at the edge of grains, the secondary enlarged edge is formed (Figure 2c & 2d). At the same time, the contact between grains gradually changes from linear contact to suture contact.

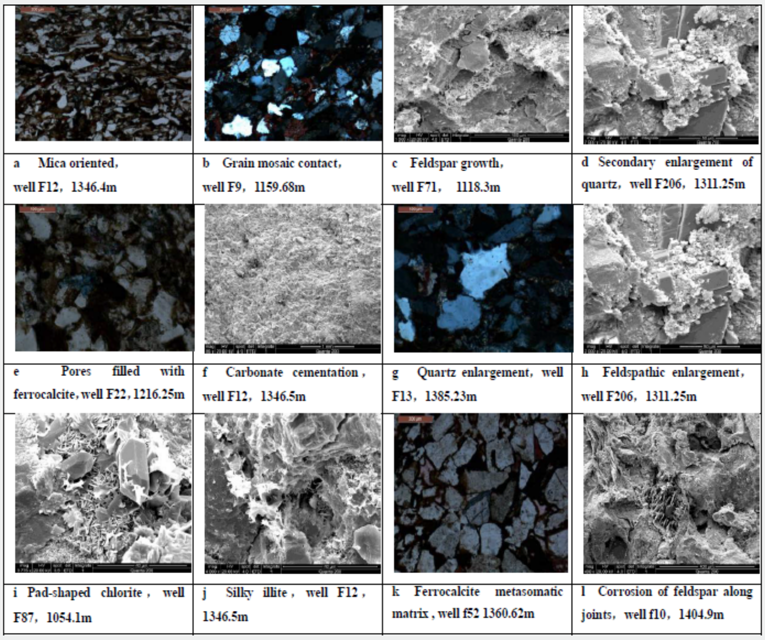

Figure 2: Diagenesis of Chang 8 Reservoir in Jiangjiachuan Area.

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Cementation

Cementation refers to the process of supersaturation precipitation of crystalline minerals in diagenetic fluid. Cementation clogging pores and reducing pore volume are unfavorable factors for pore development [2] According to the observation and analysis of rock thin sections, casting thin sections and scanning electron microscopy, three types of cementation are mainly developed in the study area: carbonate cementation, siliceous cementation and clay mineral cementation.

Carbonate cementation

Carbonate cement is common in the Chang 8 reservoir, mainly including ferrocalcite, calcite, ankerite (Figure 2e & 2f). The calcite filled in pores formed in the early stage can not only inhibits the compaction of the reservoir, but also prevents the entry of cement from outside. In the late stage, the carbonate cement is dissolved by organic acid, which greatly increases the pore volume of the reservoir and improves the properties of the reservoir. In the late stage, the carbonate cement is dissolved by organic acid, which greatly increases the pore volume of the reservoir and improves the physical properties of the reservoir. The ferrocalcite and ankerite formed in the late stage are mainly filled in the pores in the form of crystal stock or pore, and are difficult to be dissolved by organic acid, which is one of the important reasons for the tight and low permeability of the reservoir in the study area. The content of ferrocalcite formed in the late stage is high (average is 4.5%) and distribution widely, therefore, in general, the late stage ferrocalcite cementation dominates in study area which deteriorate the reservoir property.

Siliceous cementation

The siliceous cementation of the Chang 8 reservoir in the study area is strong, with an average content of 2.1%, mainly including quartz overgrowth (up to stage II-III), feldspar enlargement and authigenic quartz (Figure 2g & 2h). The deeper the buried depth is, the stronger the quartz is. It does not emit light under the condition of cathodoluminescence. The overgrowth quartz chokes the pores and throats, making the pore space smaller and the permeability worse. Under the scanning electron microscope observation, the authigenic quartz is in the form of a well crystallized pore filling, making the pore space smaller, but has little effect on the seepage.

Clay mineral cementation

Clay mineral cementation is a common diagenesis phenomenon in clastic sandstone diagenesis. Almost all sandstone reservoirs have a certain amount of clay minerals, such as kaolinite, illite, smectite and chlorite, which can be divided into authigenic and allogenic two types according composition, texture and distribution [3]. The main cementation of clay minerals in Chang 8 reservoir are composed of kaolinite, chlorite and illite.

Chlorite is ubiquitous in the target layer of the study area, with an average absolute content of 2.7%. According to the casting thin section and scanning electron microscope observation, chlorite in the target layer of the study area is filled in the pores and throat with leave-shaped and needle-shaped, reducing the pore space and throat, playing a destructive role in the reservoir. At the same time, it is generally attached to the surface of grains pad-shaped to form the chlorite film surrounding the grains. Although the chlorite film occupies the reservoir space and reduces the pore volume, it can resist the external compaction and prevent other cements component cementing and filling the pore space, so that the reservoir pore space can be preserved to a large extent. The chlorite film plays a constructive role in the low permeability reservoir. Use (Figure 2i) Illite content is less than kaolinite and chlorite, and the relative clay mineral content is 11.6%. Observed by scanning electron microscopy, illite is mostly bridge-like, hairy-like, scroll-like or curly on the pore wall or filled in the pores, separating the pores and throat, making the pores become micro-pores or ineffective pores, and the throat is bent and deformed, which seriously affects the reservoir capacity and percolation capacity (Figure 2j).

Metasomatism

Metasomatism is that a mineral is dissolved from clastic particles and replaced by another precipitated mineral. The newly formed mineral has a different chemical composition from the previously dissolved mineral [4,5]. The metasomatism is less developed in the study area, mainly composed of ferrodolomite metasomatic matrix and occasionally calcite metasomatic feldspar (Figure 2k). The metasomatism has a relatively small impact on the porosity and permeability of the reservoir due to its compliance with the law of mass conservation and volume preservation but enhances the heterogeneity and sensitivity of the reservoir.

Corrosion

The corrosion of pore water causes the corrosion of some clastic grains and interstitial materials to different extents, forming secondary corrosion pores, greatly increasing the reservoir space. Clastic particles, matrix and cement Detrital particles, hetero-bases, and cements in rocks, including stable siliceous cements, such as quartz, can undergo different degrees of corrosion and leaching as long as the diagenetic conditions are appropriate [6].

Through a large number of analysis and test data research, it is found that the target layer in the study area has strong corrosion effect, mainly feldspar corrosion, a small amount of debris corrosion, and fusible cement, resulting in a large number of corrosion, accounting for 42.3% of the relative content of pore types, which is one of the main reservoir spaces in the study area, greatly improving the reservoir property. The types of corrosion pores developed in the study area are intragranular dissolved pores and intergranular dissolved pores. In general, feldspar dissolves along the direction of the cleavage crack, and debris dissolves along the fracture or soluble direction (Figure 2l).

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Diagenetic Facies Division and Diagenetic Facies Plane Distribution

Reservoir heterogeneity is very important for reservoir exploitation. In addition to sedimentary heterogeneity, diagenetic heterogeneity also has a significant impact on Enhanced Oil Recovery (EOR). Diagenetic facies is the material expression of diagenetic environment, which emphasizes the observable diagenetic features of rocks at present, that is, the secondary diagenetic features of reservoir rocks, including cement composition and type, compaction and dissolution fabric, pore type and combination type, etc.

Although the current research on diagenetic facies lacks a complete set of conceptual systems and theories, and there is no uniform standard in the division and naming methods, its related research and application have become one of the hot issues in reservoir research [7-10]. The diagenetic facies combination type controls the pore permeability and microscopic pore texture characteristics of the reservoir, so the diagenetic facies division is helpful to the regional evaluation and prediction of the reservoir.

The diagenetic facies of the Chang 8 reservoir in the study area can be divided into four diagenetic facies by observing a large number of cast thin sections and microscopic diagenetic features of scanning electron microscopy, combined with microscopic pore types, and using the composite nomenclature of cement type + pore type:

a) chlorite film cementation - residual intergranular pores + feldspar dissolved pores

b) chlorite, illite cementation - residual intergranular pores + feldspar feldspar dissolution

c) illite cementation - feldspar solution pore phase

d) carbonate cemented facies

According to the standard of compaction strength, the compaction strength of each diagenetic facies is more than 30%, and the overall compaction strength is medium, which is one of the main reasons for poor reservoir properties [11-14].

Chlorite film cementation - residual intergranular pores + feldspar corrosion pores facies

In this type of diagenetic facies, since the film-like chlorite develops at the edge of the grain, it can hinder the secondary growth of quartz, so that the intergranular pores can be better preserved. Because the feldspar content is high, the feldspar corrosion makes the reservoir space increasing and improves the reservoir property. Such kind of diagenetic facies develop in a small area of Chang 8_1 and length 8_2 layers which is one of the favorable diagenetic facies types in the study area and one of the main regions of oil and gas accumulation.

The diagenetic facies type is located in the subaqueous distributary channel of the delta front, which is dominated by the Northeast provenance and mainly composed of debris arkose. The Chang 8 clastic component is composed of quartz and feldspar, the interstitial material is mainly composed of chlorite membrane and illite, and the cementation type is dominated by pore cementation. The pore types are mainly residual intergranular pores and corrosion pores, with an average porosity of 8.9% and an average permeability of $0.23\times10^{-3}\ \mu m^2$.

The chlorite film is well developed in the delta front sand body, and the hydrodynamic direction is stronger along the main subaqueous distributary channel, and the grain sorting and rounding is better. The content of quartz and feldspar in the diagenetic facies is high, and the content of debris + mica is high. Therefore, the dark minerals such as volcanic debris and biotite hydrated and precipitated Fe^{2+} and Mg^{2+}, which provided an alkaline environment rich in Fe^{2+} and Mg^{2+} for the formation of authigenic chlorite. The leave-shaped, pompon-shaped chlorite membrane mainly produces a clay membrane in the form of pore lining, and a small part is filled with pores in the form of interstitial materials, which endows the particle surface. The chlorite membrane hinders the contact of the clastic grains with the pore water, preventing the formation of secondary quartz and the precipitation of a portion of the carbonate cement, so that a considerable portion of the primary intergranular pores to be preserved. Moreover, the chlorite membrane and some rigid grains form a support grid with certain compressive resistance, which can inhibit the compaction to a certain extent, and retain some residual intergranular pores. It provides a favorable channel for the entry of acid formation water and provides a basis for the corrosion of rock debris in the later stage. However, the chlorite membrane protects the acid formation water mainly from intergranular pores, resulting in the expansion of feldspar grain intergranular pore and feldspar corrosion is relatively reduced. It greatly improves the properties of the reservoir and controls the reservoir and seepage capacity [15-19].

Chlorite membrane, illite residual intergranular pore cementation + feldspar corrosion pore facies

A large number of secondary corrosion pores produced by corrosion of feldspar and debris in the diagenetic facies greatly improve the physical properties of the reservoir and enhance its seepage characteristics. This kind of diagenetic facies is widely developed in Chang 8_1 and Chang 8_2 layers, which is one of the most important diagenetic facies types in the study area and also one of the main zones of oil and gas accumulation.

The diagenetic facies are mainly subaqueous distributary channel micro-facies and developed in the northwest and northeast directions, the same direction with provenance. The lithology is mainly debris feldspar sandstone, and the clastic composition is mainly feldspar, followed by quartz. The interstitial materials are mainly chlorite, illite, ferrocalcite, dolomite and ferrodolomite. The total corrosion of Chang 8 reservoir is 1.0%. The main type of reservoir space is feldspar corrosion pore, and the

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compaction strength of Chang 8 reservoir is 59.3%. The average porosity of Chang 8 reservoir is 8.0%, and the permeability of Chang 8 reservoir is $0.19\times10^{-3}\mu m^2$. Its physical property is ranking only next to that of chlorite membrane cementation + feldspar corrosion pore.

Illite cement-feldspar corrosion facies

The characteristic of this type of diagenetic facies is that pores are filled with kaolinite and illite, with high illite content. It developed in the northwest and northeast directions in the subaqueous distributary channel micro-facies. The average content of illite in reservoir Chang 8 is 8.0%. The cementation type is mainly pore cementation and growth pore cementation. The pore type is mainly corrosion pores and micro-pores, with average porosity 7.01%. The permeability is reduced to $0.16\times10^{-3}\mu m^2$ while the porosity is reduced permeability, which is ranked next to the chlorite membrane cementation-residual intergranular pores+feldspar pore facies, chlorite membrane, and illite cementation-residual intergranular pores + feldspar The study area of the corrosion pore facies is more favorable for the diagenetic facies.

Carbonate cementation facies

The characteristic of this type of diagenetic facies is carbonate filling pores with high carbonate content, mainly ferrocalite with content 10.0% in Chang 8 reservoir. The main types of pores are corrosion pores and micropores, including overgrowth pores and matrix cement with porosity of 6.3% and permeability of $0.11\times10^{-3}\mu m^2$.

Such diagenetic facies region is in the northwest source region and developed distributary bay microfacies. The early carbonate cementation (mainly calcite) enhances the reservoir's capacity to resistance compaction and inhibits the entry of external cement, so that the primary pores are well preserved. These carbonate cements are later dissolved by organic acids, which greatly increase the pore volume of the reservoir. However, the carbonate cement in the late stage blocks the pores, greatly reducing the porosity and permeability of the reservoir.

Diagenetic facies distribution

Based on the above analysis, it is known that the diagenetic facies are generally poor, belonging to low-porosity and ultra-low permeability reservoirs, developed a small amount of residual intergranular pores, feldspar corrosion pores, micropores, and the throat is micro- microlitic. For Four main diagenetic facies, that are chlorite membrane cementation - residual intergranular pores + feldspar corrosion pores and chlorite membrane, illite cementation - residual intergranular pores + feldspar corrosion pores, illite cement – feldspar corrosion and carbonate cement facies, the oil and gas storage capacity deteriorated in turn (Table 1). The chlorite film cementation-residual intergranular pores + feldspar corrosion pores mainly consist of residual intergranular pores and corrosion pores, with an average porosity of 8.9% and an average permeability of $0.23\times10^{-3}\mu m^2$. The Chlorite membrane, illite cement-residual intergranular pores + feldspar corrosion pores are mainly composed of intergranular pores - corrosion pores, with an average porosity 8.0% and an average permeability 0.19×10^{-3}. The illite cement-feldspar corrosion developed corrosion pores and micropores with an average porosity 7.01% and an average permeability is $0.16\times10^{-3}\mu m^2$. The carbonate cementation facies are mainly microporous with an average porosity 6.3% and an average permeability $0.16\times10^{-3}\mu m^2$.

Table 1: Physical Property Characteristics of different Diagenetic Facies.

No.	Diagenetic Facies Type	Pore Type	Porosity (%)	Permeability/ ($10^{-3}\mu m^2$)
1	Chlorite membrane cementation - residual intergranular pores + feldspar corrosion	residual intergranular pores, corrosion pores	8.9	0.23
2	Chlorite membrane, illite cement-residual intergranular pores + corrosion facies	intergranular pores corrosion pores	8	0.19
3	illite cement-corrosion facies	Corrosion pores-micropore	7.01	0.16
4	Carbonate cement	micropore, tight	6.3	0.11

The Chang 8_1 reservoir develops chlorite membrane cementation-residual intergranular pores + feldspar corrosion facies near the F206 well area, and develops chlorite membrane, illite cementation-residual intergranular pores + feldspar in the F87-F184 well area. The chlorite membrane hinders the clastic grains contact with pore water, and inhibits forming of secondary growth of quartz and the deposit carbonate cement, thereby causing a considerable portion of the primary particles are preserved and the corrosion of feldspar improves the reservoir space. The illite cementation feldspar corrosion pore facies and carbonate cementation facies of Chang 8_1 reservoir is relatively developed with good connectivity. The diagenetic facies illite and

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carbonate fill the pores, and almost no residual intergranular pores exist, which greatly reduces the porosity and permeability of the reservoir. In Chang 8_2 reservoir, the chlorite membrane cementation-residual intergranular pore + feldspar corrosion pore facies developed with good connectivity compared with chlorite membrane and illite cementation-residual intergranular pores + feldspar corrosion pore facies, which makes the reservoir space improved much (Figure 3).

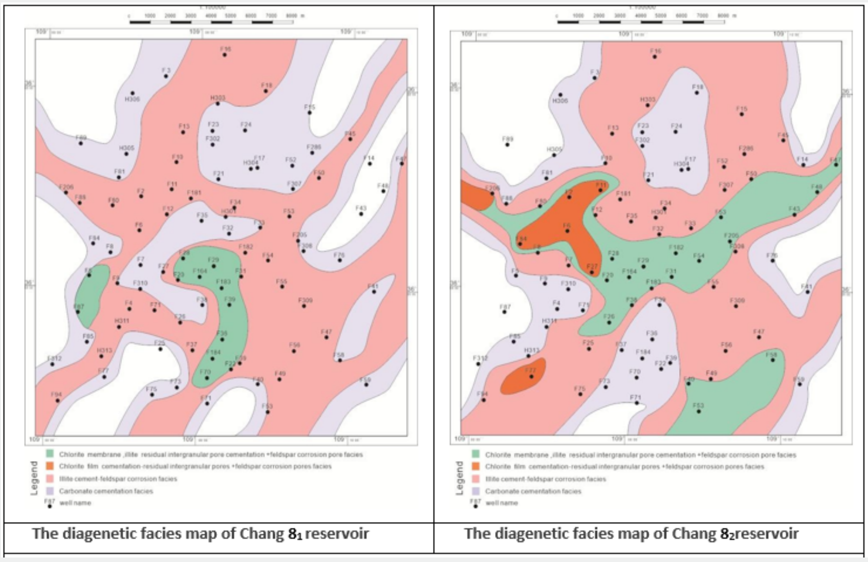

Figure 1: The Diagenetic Facies Map of Chang 8 Reservoir in Jiangjiachuan Area.

Productivity analysis of different types of diagenetic facies

According to the research results of diagenetic facies, combined with the statistical results of well testing data, the productivity of different types of diagenetic facies is analyzed (Table 2). Chlorite membrane cementation-residual intergranular pores + feldspar corrosion pore facies have the highest oil production, with initial monthly oil production (10.54 ~154) t / month and average 69.8t/month, initial monthly water cut 13.7%~84.3% and average 53.54%. The oil production of Chlorite membrane , illite-cementation-residual intergranular pores + feldspar corrosion pore facies is relative high, with initial monthly oil production(0~24.0)t/month and average 9.27t/month, initial monthly water cut 42.0%~84.3% and average 70.4%. The oil production of illite cementation-feldspar corrosion facies is relatively low, with initial monthly oil production (0~21.0)t/month and average 4.16t/month, initial monthly water cut 31.0%~100% and average77.9%. Carbonate cement facies has the lowest production, with initial monthly oil production (0~8.6) t/month and average 1.48t/month, initial monthly water cut 0~100% and average 71.5%.

Table 2: Relationship between different Diagenetic Facies and Productivity.

Diagenetic Facies	Initial monthly production (t/Month)		Water Cut %	
	Flow rate	average	Flow rate	average
Chlorite membrane cementation-residual intergranular pore + feldspar corrosion pore facies	10.54~154	69.8	13.7~84	53.54
Chlorite membrane , illite-cementation-residual intergranular pore + feldspar corrosion pore facies	0~24.0	9.27	42.0~84.3	70.4
illite cementation-feldspar corrosion facies	0~21.0	4.16	31.0~100	77.9
Carbonate cementation	0~8.6	1.48	0~100	71.5

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In summary, the highest oil production is chlorite membrane cementation-residual intergranular pores + feldspar corrosion pore facies. The second is chlorite membrane, illite cementation-residual intergranular pores + feldspar corrosion facies. The third is illite cementation-feldspar corrosion pore facies; and the lowest oil production is carbonate cementation facies. The lowest water cut is chlorite membrane cementation-residual intergranular pores + feldspar corrosion pore facies (Figure 4).

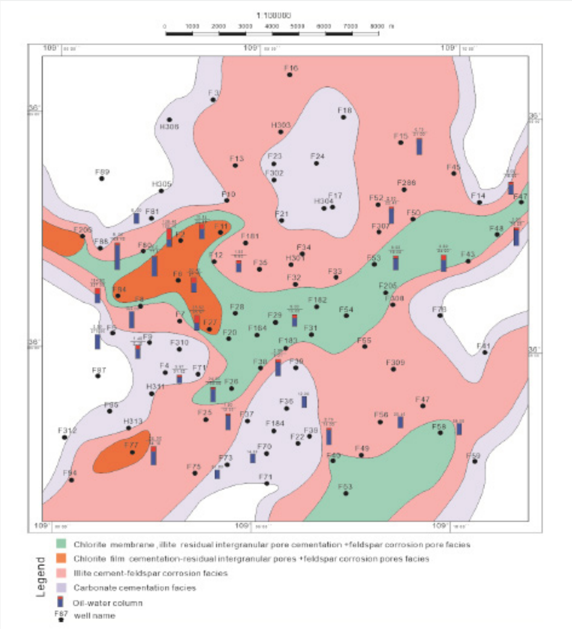

Figure 4: The Relationship Map of Diagenetic Facies and Productivity of Chang 82 Reservoir in Jiangjiachuan Area.

Conclusion

a) The diagenesis of Chang 8 formation in Jiangjiachuan area is complex and diverse. From the early stage to the late stage, it mainly experienced compaction (pressure corrosion), cementation, corrosion and less metasomatism.

b) There are four diagenetic facies in the Chang 8 reservoir in the study area: Chlorite membrane cementation-residual intergranular pore + feldspar corrosion pore facies, Chlorite membrane , illite-cementation-residual intergranular pore + feldspar corrosion pore facies, illite cementation-feldspar corrosion facies and carbonate cementation. The oil and gas storage capacity deteriorates in turn.

c) The mixed pores diagenetic with strong corrosion and weak cementation have the best oil and gas accumulation and permeability ability. The microporosity diagenetic with strong compaction and cementation have the worst oil and gas accumulation and permeability. Different types of diagenetic facies have different distribution characteristics, thus controlling the distribution of sand bodies, and the high-quality reservoirs are closely related to diagenetic facies.

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