

Diagenetic Facies Characteristics of Low-contrast Reservoirs in Chang 8₂ Formation in Huanxian Area and Their Influence on Oil-water Distribution

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Abstract: The Chang 8₂ reservoir in Huanxian County is a low-contrast reservoir, and its oil-water relationship is complex, and log-identification fluids are difficult to identify. Through observation and statistics under the microscope of casting thin section, the diagenetic facies triangle map consisting of compaction rate, cementation rate, and dissolution rate was used to quantitatively divide and identify the diagenetic facies. The diagenetic facies of the Chang 8₂ reservoir can be divided into dissolution-green mud. Stone cementation, dissolution-carbonate cementation, carbonate cementation, carbonate-chlorite cementation and mudstone compaction. Based on this, combined with comprehensive analysis of diagenetic facies and test data, the distribution laws of high-yield oil layers, high water-blocking layers, and conventional water layers are summarized to better improve the success rate of low-contrast reservoir exploration.

Keywords: Low-contrast reservoir; diagenetic facies; Chang 8₂ reservoir; Huanxian.

1. Introduction

The oil-water relationship of Chang 8₂ oil-bearing formation in huanxian area is complex, and its fluid contains conventional reservoirs, conventional water layers, high-resistivity water layers, etc^[1]. Because the reservoir has the characteristics of low contrast logging, the resistivity has certain limitations in distinguishing conventional reservoirs from high-resistivity water layers. By studying the influence of diagenetic minerals, diagenetic stage, diagenetic environment and diagenetic evolution sequence on reservoir pore structure and reservoir physical properties, the study of diagenetic facies is carried out on this basis^[2-6]. Diagenesis plays a decisive role in the formation and distribution of reservoirs. Therefore, in-depth study of diagenesis facies is crucial to accurately predict the spatial location of high-quality reservoirs and evaluate the favorable areas of oil and gas reservoirs. The predecessors studied the reservoir characteristics of the Chang 8 reservoir group in Longdong area, but the research results did not involve the study of the distribution of diagenetic facies in oil and water^[5-6]. In this paper, the quantitative analysis method of diagenetic facies triangle diagram is used to discuss the distribution and characteristics of diagenetic facies. This method not only helps to understand the rules and differences of diagenetic facies in different regions, but also provides a powerful tool for comparing the change trend of diagenetic facies distribution in different geological periods. In this way, we can more accurately evaluate the influence of diagenesis on sedimentary environment and its evolution process. On the

basis of quantitative diagenetic facies analysis of Chang 8₂ oil layer group, it is of great significance to explore the formation mechanism of diagenetic facies and its influence on oil-water distribution rule, which is of great significance to improve the exploration effect of low contrast regional reservoirs. By accurately analyzing the characteristics and rules of diagenetic facies belts, it can effectively guide exploration personnel to identify favorable reservoirs more accurately, thus significantly improving the success rate of drilling and laying a solid foundation for efficient development.

2. Low Contrast Reservoir Electrical Characteristics

Using the relevant identification data of oil test, logging and coring in this area, the related characteristics are studied by the cross plot of deep induction resistivity and water saturation and the cross plot of porosity (Fig.1). The traditional four-property relationship chart is not ideal for the fluid identification of the Chang 8₂ reservoir as a logging low-contrast reservoir. It can be seen from the figure that the high-resistance water layer and the oil layer cannot be identified. Through statistics, the resistivity range of the high-resistivity water layer is 40-397 Ω.m. Conventional water layer is generally less than 40 Ω.m. The resistivity of oil layer is greater than 40 Ω.m. Therefore, the traditional logging methods have significant limitations on the identification of high-resistivity water layers, and it is urgent to find other methods that can identify or predict high-resistivity water layers.

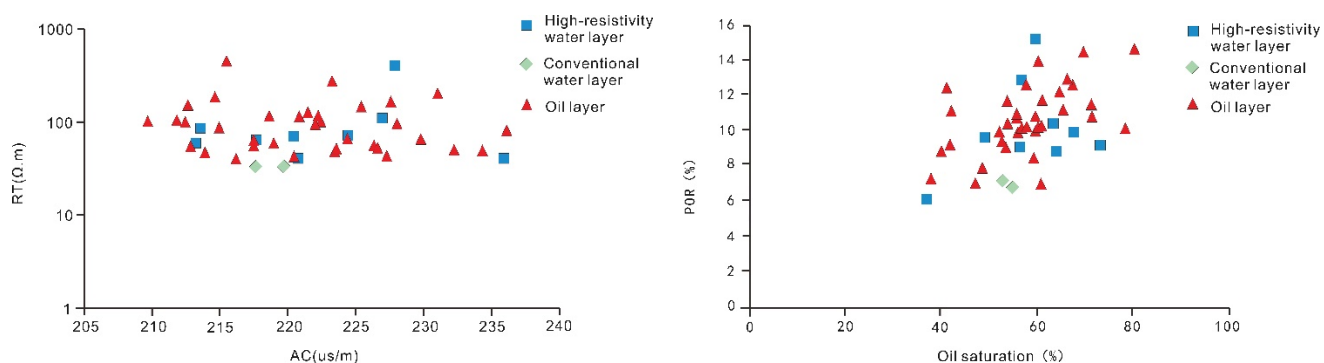


Figure 1. Four-property relationship diagram of Chang 82 low contrast reservoir

3. Diagenetic Facies Characteristics

In this study, combined with casting thin section data, the concept of diagenesis coefficient is introduced, and its influence on diagenesis is quantitatively characterized. The basic parameters are as follows :

(1) Original porosity = $20.91 + 22.9 / S_o$, where S_o is the sorting coefficient in particle size analysis, $S_o = (Q_2 / Q_1) / 2$; Q_1 is the particle diameter at 75% of the cumulative probability curve, and Q_2 is the particle diameter at 25% of the cumulative probability curve^[7].

(2) Compaction rate = (original pore - (present intergranular pore + cement)) / original porosity

(3) Cementation rate = cement volume / (cement volume + present intergranular pore volume)

(4) Dissolution rate = dissolution pore volume / surface porosity

Therefore, the diagenetic facies triangle diagram (Fig.2), composed of compaction rate, cementation rate and dissolution rate was constructed. The diagenetic facies of the samples in the study area are mainly dissolution-cementation filling phase and cementation filling phase.

The porosity and permeability of sandstone are analyzed in depth, and the pore structure is further explored. The

comprehensive consideration of these parameters provides important information for understanding the internal structure of rock. The diagenetic facies belt in the study area includes the following five types : dissolution-chlorite cementation facies, dissolution-carbonate cementation facies, carbonate cementation facies, carbonate-chlorite cementation facies and mudstone compaction facies (Fig.7).

①Dissolution-chlorite cementation facies : In the study area, this type of sedimentary facies is the most favorable oil and gas enrichment facies belt, which mainly develops feldspar dissolution pores and secondary intergranular residual pores formed by chlorite film, and the reservoir physical properties are good (Fig.3). The chlorite film forms a substrate-type cementation at the periphery of the particles. It forms an effective anti-compaction effect and is beneficial to the protection of residual intergranular pores. On the other hand, the quartz crystal substrate is mainly cemented by chlorite film and effectively inhibits the formation of quartz secondary enlargement. Under this influence, the residual intergranular pores are protected to a certain extent, and the porosity and connectivity of the diagenetic facies are good. Based on the above situation, this cementation facies can create better conditions for oil and gas migration.

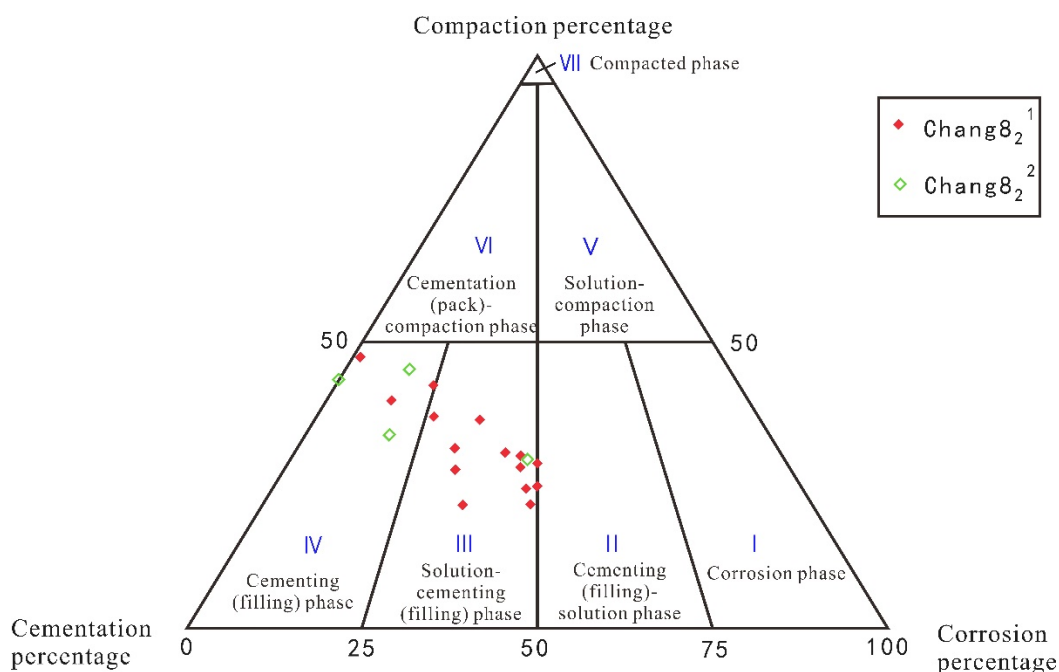


Figure 2. The Chang 8₂ diagenetic facies triangular projection point diagram of the study area

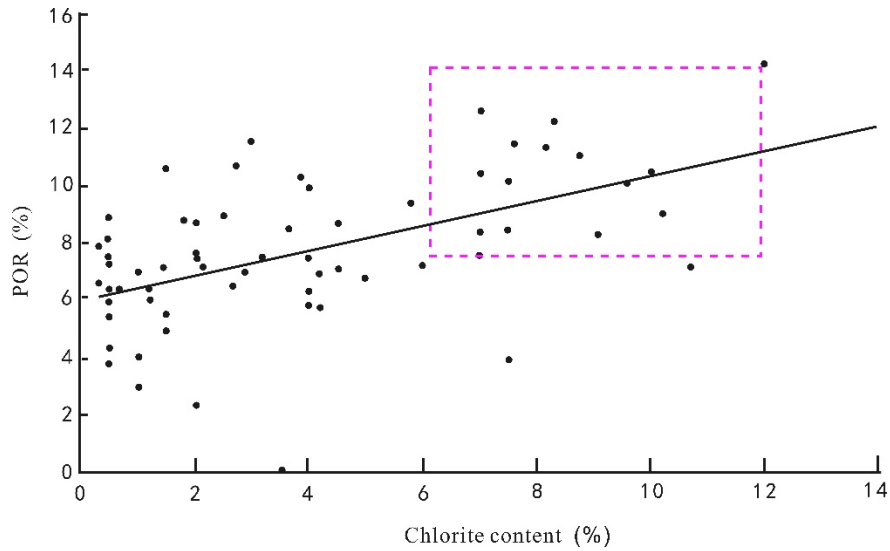


Figure 3. The relationship curve between chlorite content and physical properties of Chang 8₂ reservoir

The Chang 8₂ dissolution-chlorite cementation facies in the study area are mainly distributed in the Li 168-Li 258-Li 177-Li 34 well area, Li 87, Li 20-Mu 65 well area, Li 179, Mu 88-Li 146, Li 87-well area (Fig.7).

②Dissolution-carbonate cementation facies : In the study area, this type of sedimentary facies is a more favorable oil and gas enrichment facies belt, mainly developing secondary intergranular residual pores formed by dissolution pores-carbonate cements. The dissolution-carbonate cementation facies of Chang 8₂ in the study area are mainly distributed in Li 200, Bai 279, Li 289-Li 173-Li 63 well area, Mu 208, Li 20-Mu 65, Li 179, Mu 88-Li 146, Li 87-well area (Fig.7).

③Carbonate cementation facies : The development range of carbonate cementation facies in the study area is relatively wide, which is mainly developed in the flank of the river channel or where the reservoir physical properties are relatively poor. The sandstone in the large burial and closed diagenetic environment for a long time undergoes a slow exchange process in water. In the high temperature and low oxygen environment, the Fe^{3+} ions in the medium are reduced to Fe^{2+} . When CO_3^{2-} ions interact with Ca^{2+} and Mg^{2+} ions to form calcite and dolomite, Fe^{2+} ions enter the mineral lattice and form some iron carbonate minerals, such as iron calcite and iron dolomite. Although a small amount of intergranular diagenetic carbonate cementation reduces the influence of compaction on the original intergranular pores to a certain extent, late diagenetic carbonate cementation is common in

lithofacies sandstone, forming a carbonate cemented tight layer laterally^[7], which seriously affects the physical properties of the reservoir. In addition, the carbonate in this sandstone has extensive metasomatism of clastic feldspar, biotite, quartz, clastic and clay minerals. The complex basement and micro-fractures formed in the early stage eventually lead to the densification of sandstone and the serious loss of reservoir performance (Fig.4). Therefore, this type of diagenetic facies often produces water and does not have oil production capacity.

④Carbonate-chlorite cementation facies : The diagenetic facies is in the area of medium-poor physical properties. This lithofacies is relatively limited in the study area (Fig.7), mainly developed in Huan 9, 9-Mu 82 well area, Li 58-Li 120 and Li 49-Xi 271 well area.

⑤Compaction facies : The lithofacies are more developed in the interdistributary bay and the flank of the underwater distributary channel, with strong compaction and weak dissolution (Fig.7). Due to the small particle strength, the content of plastic particles and cuttings is high, which is easy to be compacted. When the influence of strong compaction is encountered, the pore content is low, the fluid is difficult to flow and the dissolution is weak. Therefore, the physical properties of the diagenetic facies belt are poor, the porosity is generally less than 6%, and the permeability is less than $0.1 \times 10^{-3} \mu m^2$, which cannot become an effective reservoir^[7-9].

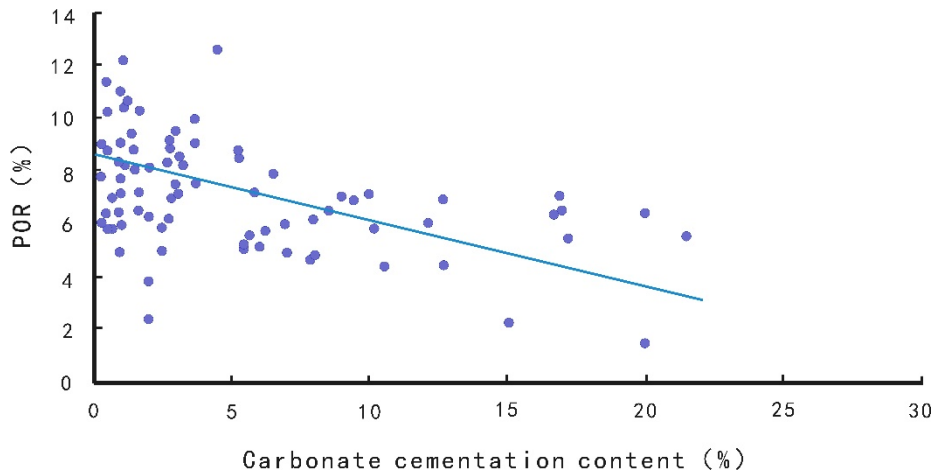


Figure 4. The relationship between carbonate content and physical properties of Chang 8₂ reservoir

4. Relationship Between Diagenetic Facies and Oil-water Distribution

The increase of carbonate content leads to the increase of resistivity. Carbonate appears in the form of cementation, which changes the pore structure of the reservoir^[8-10], fills a

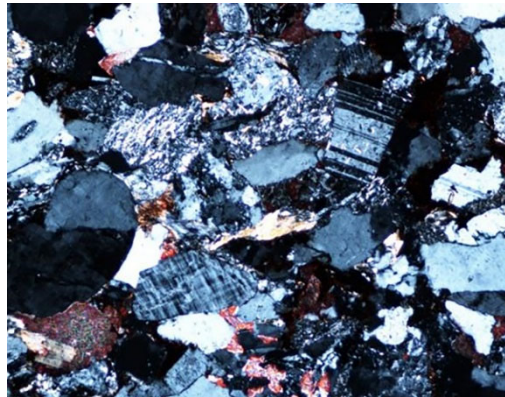
part of the pore, makes the whole lithology more dense (Fig.4, Fig.5), further affects the conductivity of the rock, and leads to the increase of resistivity^[11-12]. The content of carbonate cement in Chang 8₂ high-resistivity water layer is much higher than that in oil layer, indicating that the high carbonate content is an important factor in the formation of Chang 8₂ high-resistivity water layer in the study area (Table 1).

Table 1. Statistical characteristics of carbonate cements in the study area

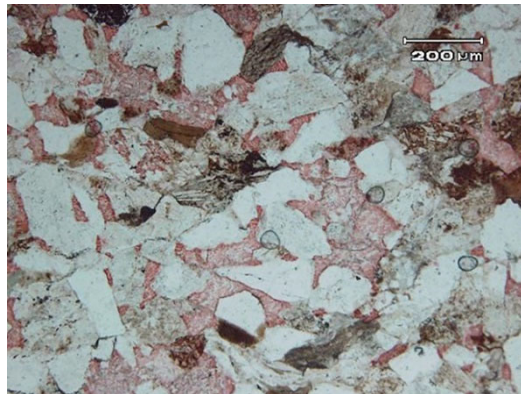
well name	Oil-water identification	resistivity ($\Omega \cdot m$)	cement							Total cement (%)
			Total carbonate	siderite	kaolinite	siliceous	feldspathic	Chlorite membrane	hydromica	
Mu 99	high-resistivity water layer	84.8	4.8	0	0.8	0	0	2.2	0	9.3
Li 63	high-resistivity water layer	40.0	10.0	0	0	1.0	0	2.0	2.0	15.0
Li 148	oil layer	198.57	2.5	0	0	0	0	0	0.5	3.0
Mu 16	oil layer	42.11	3.5	0	3.4	0.1	0	3.3	0.4	10.7
Xi 233	oil layer	51.1	1.0	0	0	0.5	0	0	4.5	6.0
Mu 207	oil layer	45.8	4.0	0	0	1	0	2.0	4.0	11.0
Li 144	oil layer	51.9	5.05	0	0	1.2	0	8.07	0.95	15.27

The reservoir contains gray matter, resulting in a significant increase in resistivity values, and the water-bearing reservoir is easily misjudged as a reservoir^[13-14]. There are chang 8₂¹ layers of high resistivity water layer in well Li 63 (Fig.6), with water production of 3.2 m³/d and resistivity of 42.0 $\Omega \cdot m$. Its resistivity detail is higher than the lower limit of reservoir resistivity by 25 $\Omega \cdot m$. The AC of 2181.1 m and 2186.8 m is 202 us/m, and the DEN increases,

which is calcareous cementation facies (Fig.6). On the plane distribution map of diagenetic facies, the well is located in carbonate cementation facies (Fig.7). The identification of these known high-resistivity water layers is based on oil testing and microscopic feature data under rock microscope, but for the untested oil well section, these high-resistivity water layers are easily identified as oil layers.



Carbonate cement, etc., Li 63, 2181.11m, 100(+) (high-resistivity water layer, Chang 8₂¹)



Carbonate cement, Mu 99, 2354.1, (high-resistivity aquifer, Chang 8₂¹), RT(70 $\Omega \cdot m$)

Figure 5. Characteristics of high-resistivity water layer under microscope

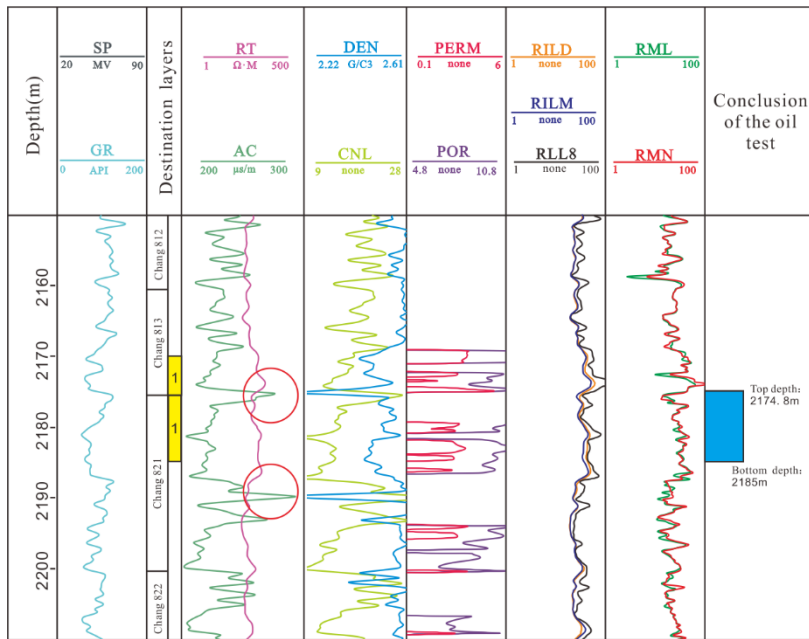


Figure 6. Electrical characteristics of Chang 8₂ high resistivity water layer in Li 63 well

The reservoir diagenetic facies in the study area are mainly dissolution-chlorite cementation, dissolution-carbonate facies, carbonate-chlorite, carbonate cementation facies and compaction facies (Fig.7). Among them, the first three are more favorable diagenetic facies, generally located in the place where the sand body is thicker, and the porosity is 8-10%. The carbonate cementation facies is generally located in the place where the sand body is thin, and its porosity is generally 6-8%. Based on the diagenetic facies and oil test data, the oil layer is distributed in the dissolution-chlorite cementation, dissolution-carbonate phase and carbonate-chlorite phase. The conventional water layer is distributed in the carbonate-chlorite cementation phase in the southeast of the study area, and the high-resistance water layer well is located in the calcareous cementation phase.

5. Conclusion

1. Through the casting thin section data, the diagenesis is quantitatively characterized by the diagenesis coefficient. According to the compaction rate, cementation rate and dissolution rate, the diagenetic facies triangle diagram is established, and the diagenetic facies triangle diagram is analyzed and summarized. It is known that the study area mainly develops dissolution-cementation filling phase and cementation filling phase. The study area can be divided into five diagenetic facies belts : dissolution-chlorite cementation facies, dissolution-carbonate cementation facies, carbonate cementation facies, carbonate-chlorite cementation facies and mudstone compaction facies.

2. The traditional logging method has limitations for the logging of low contrast reservoirs in the Chang82 oil layer group, especially in the identification of high-resistivity water layers. The resistivity range of the high resistivity water layer is 40-397Ω.m, while the conventional water layer is mostly < 40Ω.m, and the oil layer is greater than 40Ω.m. The traditional methods have obvious limitations in the identification of high-resistivity water layers, and it is necessary to find other methods that can identify or predict high-resistivity water layers.

3. The dissolution-chlorite cementation phase is a high-quality oil and gas enrichment facies belt with good physical

properties, which is conducive to protecting residual intergranular pores. The oil and gas enrichment ability of corrosion-carbonate cementation facies and carbonate-chlorite cementation facies is poor. In contrast, carbonate cementation facies and compaction facies do not have good reservoir performance and are more likely to produce water. The relationship between the distribution of diagenetic facies and oil-water distribution provides an important basis for improving the success rate of low-contrast reservoir exploration.

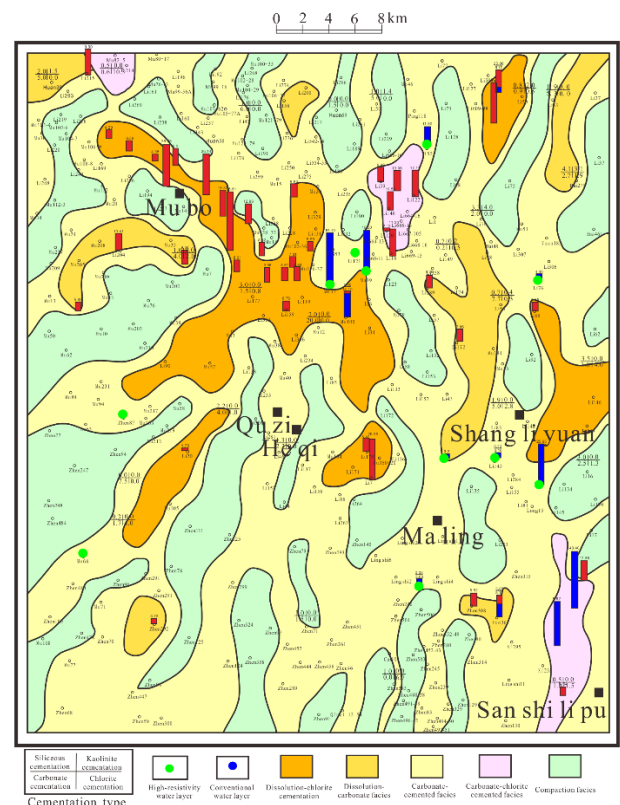


Figure 7. Composite diagram of diagenetic facies and oil test (Chang 8₂)

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References

- [1] Wu Yingzhong, Duan Yi, Zhao Yang, et al. Study on the identification standard of Chang 81 low resistivity reservoir and high resistivity water layer in Longdong area [J]. *Special Oil and Gas Reservoirs*, 2017, (1): 38-42.
- [2] Li Jin, Du Xiangqian, Li Jiazun, et al. Diagenetic facies division of low permeability sandstone based on multi-parameter quantitative evaluation [J]. *Fault Block Oil and Gas Reservoir*, 2016, 23(5): 554-559.
- [3] Chen Xianliang, Ji Youliang, Yang Keming. Quantitative diagenetic facies characteristics of reservoir in the fourth member of Xu formation in the middle part of West Sichuan depression [J]. *Fault-block Oil and Gas Reservoirs*, 2017, 24(1): 5-9.
- [4] Lai Jin, Wang Guiwen, Wang Shunan, et al. Research status and progress of diagenetic facies of clastic reservoir [J]. *Advances in Geoscience*, 2013, (1): 39-50.
- [5] Ren Dazhong, Sun Wei, Wei Hu, et al. Diagenetic facies types and microscopic pore structure characteristics of Chang 81 reservoir in Huaqing Oilfield [J]. *Modern Geology*, 2014, (2): 379-387.
- [6] Chen Dayou, Zhu Yushuang, Zhang Jiaosheng, et al. Diagenesis and favorable diagenetic facies belt of Chang 8 reservoir in Maling area, Ordos Basin. *Petroleum Experimental Land quality*, 2015, (6): 721-728.
- [7] Tian Yifan. Study on reservoir evaluation of Triassic Chang 82 in Longdong H84 well area [D]. Xi'an University of Petroleum, 2018.
- [8] Xiao Ling, Chen Xi, Lei Ning, et al. Characteristics and main controlling factors of shale oil reservoir in Chang 7 member of Triassic in Heshui area of Ordos Basin. *Lithologic reservoir*, 2023, 35(2): 80-93.
- [9] Wei Qinlian, Zhang Huifang, Han Yonglin, et al. Microscopic Pore Structure Characteristics and Fluid Mobility in Tight Reservoirs: A Case Study of the Chang 7 Member in the Western Xin'anbian Area of the Ordos Basin, China. *Minerals*, 2023, 13, 1063.
- [10] Xiao Ling, Yang Leilei, Zhang Xuwen, et al. Densification Mechanisms and Pore Evolution Analysis of a Tight Reservoir: A Case Study of Shan-1 Member of Upper Paleozoic Shanxi Formation in SW Ordos Basin, China. *Minerals*, 2023, 13, 960.
- [11] Wei Qinlian, Zheng Rongcai, Xiao Ling, et al. Analysis of Chang 6 reservoir characteristics and influencing factors in Wuqi area of Ordos Basin [J]. *Lithologic reservoirs*, 2007, 19(4): 45-50.
- [12] Xiao Ling, Wei Qinlian, Lu Yujuan. Study on reservoir densification and main controlling factors of high-quality reservoir of Chang 6 formation in Nanliang area of Ordos Basin. *Journal of Yan'an University*, 2017, 36(4): 12-16.
- [13] Liu Jian, Han Jingjing, Wang Bo, et al. Discussion on influencing factors of high resistivity water layer in Chang 8 reservoir of Xifeng oilfield [J]. *Petrochemical applications*, 2016, (3): 111-114.
- [14] Zhang Qingguo, Wang Shuo, Feng Xiaodong, et al. Genetic Analysis and Identification method of High resistivity Water layer in Tahe Daqingzijing Oilfield [J]. *Science and Technology and Engineering process*, 2011, 11(34): 8444-8451.