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Study on reservoir characteristics of Chang2 reservoir in southwest Ordos Basin

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ABSTRACT

In order to clarify the reservoir characteristics of the Chang2 oil formation in the GQ block of the Ordos Basin, the reservoir characteristics and pore structure of the Long 2 oil formation in the study area were investigated using experimental data such as cast thin section, scanning electron microscope (SEM) and mercury pressure curve. The results show that the Chang2 oil formation in the study area mainly develops medium sandy fine-grained feldspathic sandstone, and the pore types are rock dissolution pores and intergranular pores. The reservoirs of the Chang2 oil formation group in the study area were evaluated and classified by applying piezomercury curve banding, and the reservoirs were classified into three categories: Small pore-medium fine-throat type-medium pore-medium fine-throat type, Fine pore-micro-throat type and Mesoporous-coarse throat type. In the study area, most of the reservoirs in Chang2 are Small pore-medium fine-throat type-medium pore-medium fine-throat type, accounting for 50% of the total, while Mesoporous-coarse throat type accounts for 34.7% and Fine pore-micro-throat accounts for 15.3% of the total. The Chang2 oil reservoir in the study area is mainly developed as a general reservoir.

KEYWORDS

Reservoir characteristics; Pore structure; Mercury injection; Chang 2 oil formation; Ordos basin.

1. INTRODUCTION

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At present, production from low-permeability reservoirs in China accounts for more than 70 per cent of domestic crude oil production capacity. Compared with high-permeability reservoirs, low-permeability reservoirs have the basic characteristics of strong inhomogeneity, poor physical properties and complex pore structure. The Ordos Basin is the largest oil and gas production area in China, and one of the major oil reservoirs, the Chang2 reservoir of the Yanchang Group, is a typical low-permeability reservoir. In recent years, the Chang2 reservoir in the southwestern part of the Ordos Basin has been extensively developed, which is an important part of the region to increase storage and production[1-3].

Therefore, it is of great significance to systematically carry out the reservoir characterisation study of the Chang2 reservoir in the southwestern part of the Ordos Basin, in order to clarify the petrological characteristics, physical properties and pore structure characteristics of this kind of reservoir, which is conducive to finding the distribution of high quality reservoirs and is of great significance to the study of low permeability reservoirs. This paper takes the Chang2 oil formation group reservoir in the GQ block of the Ordos Basin as an example, and uses the methods of core description, scanning electron microscope identification and high-pressure mercury pressure to study the characteristics of the low-permeability reservoir, which provides an important experimental basis for the further exploration and development of low-permeability oil reservoirs[4-6].

2. BASIC INFORMATION OF THE RESEARCH AREA

The Ordos Basin covers not only the three provinces of Shaanxi, Gansu and Ningxia, but also parts of Shanxi and Inner Mongolia. The basin is now bounded by the Helan Mountains - Liupan Mountains tectonic belt on the western margin, the Qinling orogenic belt on the southern side, the Luliang Mountains uplift on the eastern side and the Yinshan Mountains uplift on the northern margin, with an area of about 25×104 km2 (Fig.1).

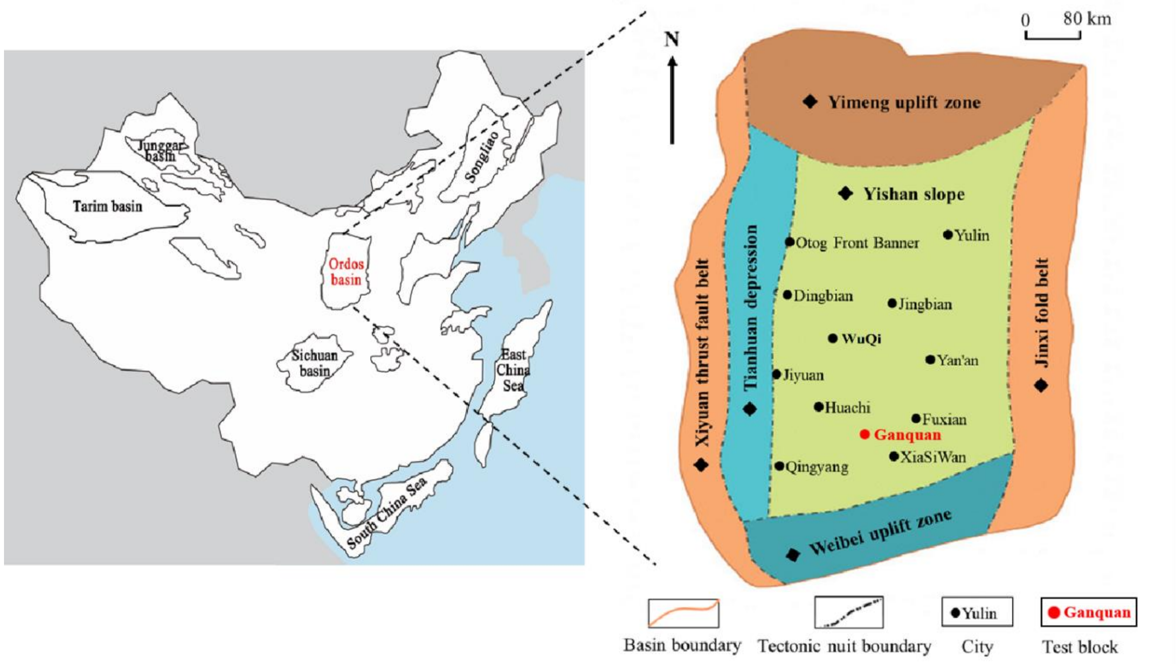


Fig.1 Tectonic unit map of Ordos Basin

The overall tectonic morphology of the Ordos Basin is a north-south oriented asymmetric large oblique rectangular basin that is broad and gentle in the east and steep and narrow in the west.

The internal tectonics of the basin is relatively simple, the stratigraphy is relatively gentle, and only the rim of the basin is more developed by folding and fracturing. The North Shaanxi Slope is the main part of the central Ordos Basin, formed in the Early Cretaceous, with a single westward dip, a general gradient of about 10-15m/km and a dip angle of less than 1º. The local tectonics and faults of this slope are not developed, the low amplitude nasal tectonics is more developed, and the form of the nasal tectonics is mostly irregular shape with poor direction, the two flanks are generally nearly symmetrical, the dip angle is less than 2º, the reservoir closure area is less than 10km2, and the closure height is 10~20m. This slope does not develop the dorsal tectonics with large amplitude and good closure (Fig.1). The lithology of the Chang2 reservoir of the Yanchang Formation is mainly fine-grained feldspathic sandstone and medium fine-grained feldspathic sandstone, and the pore types are mainly intergranular pores and dissolution pores, while the local development of microscopic cracks. The reservoir is a low porosity, low permeability reservoir. The reservoir type is mainly controlled by tectonics, lithology and physical properties. The local development of nasal uplift has a controlling effect on oil and gas production. The study of the sedimentary evolution process of the Ordos Basin Extension Formation concluded that with the tectonic uplift, the lake basin contracted to extinction during the depositional period of the Chang2 layer, the Chang2 layer of the GQ block is a braided river river deposition, the river is a low curvature river deposition, The material source of the study area during the depositional period of the Long 2 layer is in the northeast direction, and in the direction of the material source, the sand is distributed in a stripe-like manner, and the sand of the river channel is more developed, and the sand is in a multi-layered structure, with a relatively coarser grain size, which is a main gathering area of hydrocarbons. It is the main accumulation area for oil and gas. By analysing the core data, combining with the well logging data, oil test and production situation, according to the principle of rotation comparison, the Chang2 oil formation group in the study area is divided into three sand groups, including Chang21, Chang22 and Chang23, of which Chang22 is the main oil-bearing layer.

3. STUDY ON RESERVOIR CHARACTERISTICS

3.1. Petrological characteristics of reservoir

3.1.1. Clastic composition characteristics

The Chang2 reservoir was mainly deposited by river sand dams, generally buried at a depth of 600~750m, with general petrological characteristics of low compositional maturity and high structural maturity. The pore types are mainly intergranular pores, with a small number of feldspar intragranular pores, mould pores, chlorite intergranular pores, mica and other intragranular pores, and the physical characteristics of the reservoir are characterised by low porosity and low seepage.

The lithology of the Chang22 reservoir in Block GQ is dominated by greyish-white fine feldspar and medium fine feldspar sandstone, followed by medium, very fine, fine medium feldspar, fine calcareous feldspar, medium feldspar in silt gravel and fine clastic feldspar sandstone. The sandstone thin section data of 51 samples were compiled and counted, and the results showed that the sandstone of the Chang2 reservoir is mostly light grey to greyish-white calcareous fine-grained feldspathic sandstone, massive, and the main mineral components of the sandstone of the Chang22 reservoir are quartz (34%-53%, average 40.1%), feldspar (32%-61%, average 48.7%) and clasts (2-18%, average about 7.2% (Fig.1, Fig.2). Clasts are mainly composed of igneous clasts, followed by sedimentary clasts, with metamorphic clasts being the least abundant (Table 1). Igneous rock clasts consist of granite, igneous rock and cryptocrystalline rock, sedimentary rock clasts consist of siltstone, mudstone, dolomite and greywacke, and metamorphic rock clasts consist of schist, slate and millimetalite. The sandstone contains small amounts of heavy minerals, including stable fractions of zircon and garnet, but also poorly stable apatite and chlorite (Table 2). The colluvium consists mainly of carbonate minerals (calcite, dolomite), silica, soda feldspar and clay minerals. The sandstones are mostly diagonally laminated, grooved, cross-laminated and mixed at the base; mud pebbles of 0.5~1 cm in diameter are commonly found in the lower part of each small eddy, and the sandstones contain a large number of ferruginous nodules of 0.5-1.5 cm in diameter, and a large number of bioturbation formations are seen in the muddy siltstones. The sandstone level is enriched with large amounts of black mica and some of the beds contain a large number of carbonaceous bands, and scouring and filling structures are seen at the bottom of each circle[7].

Table 1. Detrital composition distribution

Composition	Quartz		Feldspar		Debris	
	Range	Mean	Range	Mean	Range	Mean
Content (%)	34~53	40.1	32~61	48.7	2~18	7.2

Table 2. Statistical table of debris composition

Igneous debris %				Metamorphic debris%							Sedimentary debris%				
granite	Eruptive	Cryptocrystalline rock	total	hypite	quartzite	schist	phyllite	slate	Metamorphic	total	siltstone	Mud stone	dolomite	limestone	total
1.31	0.1	2.91	4.32	0.00	0.00	0.53	1.02	0.04	0.00	1.59	1.45	1.36	0.02	0.00	2.83

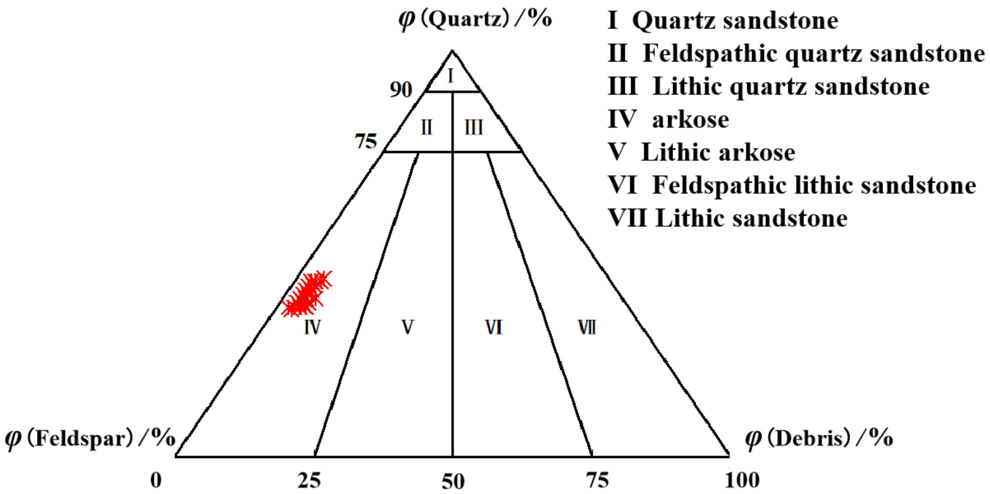


Fig.2 Classification map of sandstone

3.1.2. Composition characteristics of interstitial materials

The fills of the Chang22 clastic sandstone consist of heterogeneous bases and colluvium. The heterogeneous base consists mainly of chlorite and mica, and the colluvium consists mainly of carbonate minerals (calcite, dolomite), silica, sodium feldspar and clay minerals (Fig. 3, Table 3).

Table 3. Interstitial composition distribution table

Type	Matrix		Cement				
	Mica	Chlorite	Calcite	Dolomite	Albite	Siliceous	Clay Minerals
Content(%)	6.06	4.42	6.76	3.14	0.53	1.09	2.74

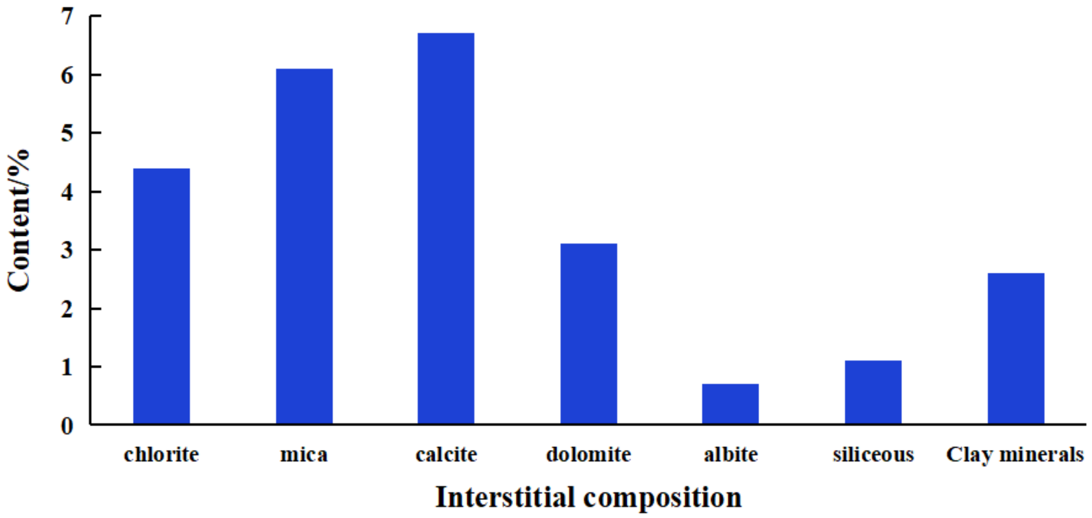


Fig.3 Interstitial composition histogram

Carbonate content is highest in the fill of the Chang22 Formation, where the average value of calcite is 6.76%, accounting for 27.3% of the total fill, and the average value of dolomite is 3.14%, accounting for 12.7% of the total fill, and both accounting for 34.06% of the total fill. Mica is second only to carbonate with an average of 6.06% and 24.5% of the total fill (Fig. 3).

Chlorite output states include both pore lining and pore filling modes, with the most dominant output state being the pore lining mode, i.e. enveloped chlorite. Siliceous and feldspathic siliceous colluvium is not an important authigenic mineral in the reservoir sandstones and its precipitation is not the main cause of rock compaction. Most of the siliceous cement is in the form of dispersed crystals or around the edge of detrital quartz growth, forming a large edge enhancement and blocking part of the intergranular pore space; feldspar is mostly in the form of secondary enhancement in the form of pore space filling.

The cast thin section and scanning electron microscope data show that chlorite mostly grows along the surface of the particles in the form of an envelope with an envelope thickness of 3~5μm, and individual samples have an envelope thickness of 5~10μm, and the morphology of most of them is in the form of acicular or bladed vertical growth along the surface of the particles.

The data show that the cement content, especially the high chlorite content (e.g. when the chlorite content is 9%), is low in porosity (porosity 4.5%); on the contrary, when the chlorite content is low (e.g. 1.5%), the porosity is high (up to 11.8%).

3.2. Reservoir physical characteristics

According to the core analysis data, the average porosity of the core analysis is 17.65% and the air permeability is 76.4×10-3μm2. Statistics of core analysis data from 165 blocks in the area show that the average porosity of the Chang22 reservoir is 13.6% and the median porosity is 15.7% (Table 4).

Table 4. Reservoir porosity and permeability statistics table

Layer	Porosity (%)				Permeability /$\times 10^{-3}\mu m^2$				Samples number
	Max	Min	Mean	Mid	Max	Min	Mean	Mid	
Chang 2^2	18.3	3.8	13.6	15.7	24.7	0.02	4.49	2.78	440

According to the statistics of the physical analysis data of Block 165, the physical properties of the Chang22 reservoir in Block GQ are as follows: the minimum value of porosity is 3.8 per cent, the maximum value is 18.3 per cent, the average value is 13.6 per cent, the distribution of main porosity ranges from 8.2 per cent to 16.9 per cent, accounting for 80 per cent of the total porosity samples, and the average porosity above the lower limit is 15.2 per cent. 6 percent of the total porosity samples, and the average porosity above the lower limit is 15.2 percent; the minimum value of permeability is 0.02×10-3μm2, the maximum value is 24.7×10-3μm2, the average is 4.49×10-3μm2, the distribution of main permeability is from 0.211 to 5.99×10-3μm2, accounting for 70.9% of the total permeability samples, and the average permeability above the lower limit is 1.44×10-3μm2 (Fig.4, Fig.5). The above physical parameters indicate that the reservoir is a low porosity, extra-low permeability reservoir.

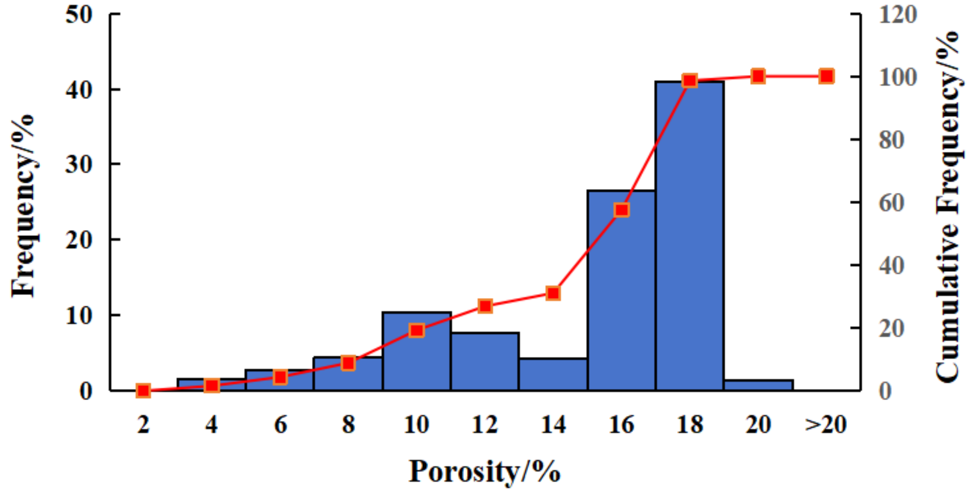


Fig.4 Porosity frequency histogram

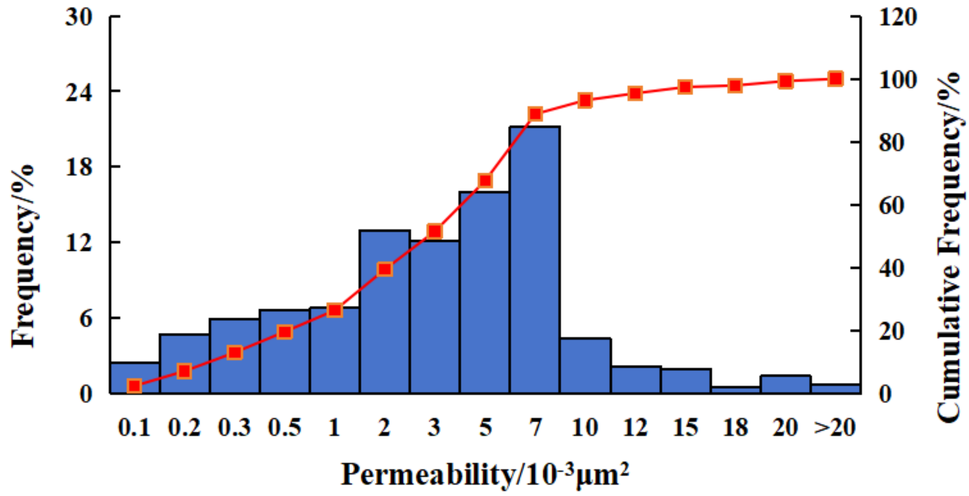


Fig.5 Permeability frequency histogram

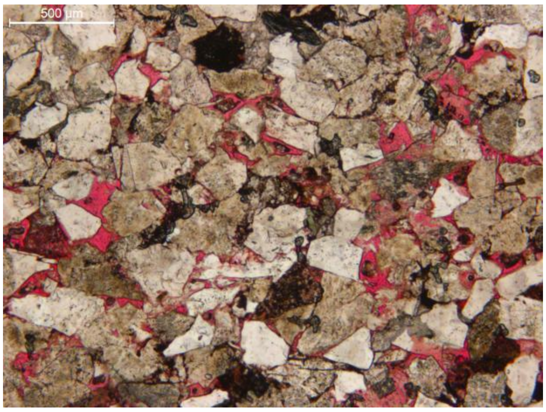
There are many factors that influence the physical properties of reservoirs. On the one hand, the geological depositional factors of sandstone reservoirs, especially their compositional maturity and structural maturity, have a greater influence on reservoir physical properties, and the particle size of the constituents also plays a crucial role; on the other hand, there are post-generation effects, including compaction, compression and dissolution, autochthonous mineral filling and cementation, and dissolution and erosion. Throughout its long geological history, the Chang22 sandstone has evolved through complex physical and chemical effects into the low porosity, low permeability reservoir it is today.

3.3. Reservoir pore structure characteristics

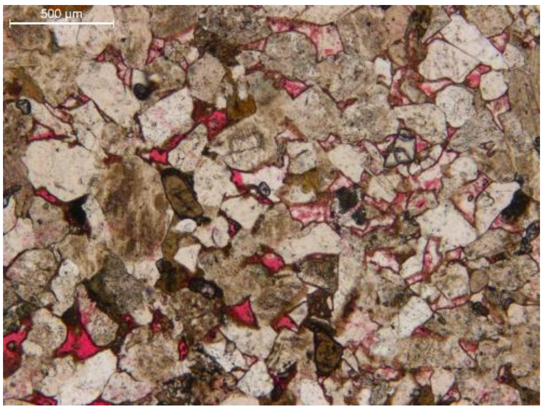
Through core and thin section observation and statistical analysis by scanning electron microscopy, the main pore types developed in the Chang22 reservoir of the GQ block are secondary dissolution pores (including intergranular and intragranular pores), intergranular pores and intragranular pores. The main pore types are secondary dissolution pores of intergranular pores, which are the main components of effective pores. The total surface porosity of the zone is 5.28%, of which intragranular micropores account for 2.65% of the total surface porosity, intergranular micropores account for 4.55%, intergranular solvular pores account for 74.8%, intragranular solvular pores account for 8.7%, and shaped pores account for 14.01% of the total surface porosity (Table 5). The residual intergranular pores are the main storage space of the Chang2 layers in the study area, which are retained after mechanical compaction or secondary increase of quartz; the intergranular dissolution pores are the pores formed by the dissolution of the edges of clay minerals, carbonate minerals and feldspars, rock chips and other detrital particles, which partially restore and enlarge the primary pores or form new secondary pores, and the pores are mostly irregular, with jagged edges or harbour-like, and the intergranular dissolution pores can improve the connectivity of the pore throats. Intergranular dissolution pores can improve connectivity between pore throats and reservoir storage capacity (Fig.6).

Table 5. Pore type of Chang2 reservoir

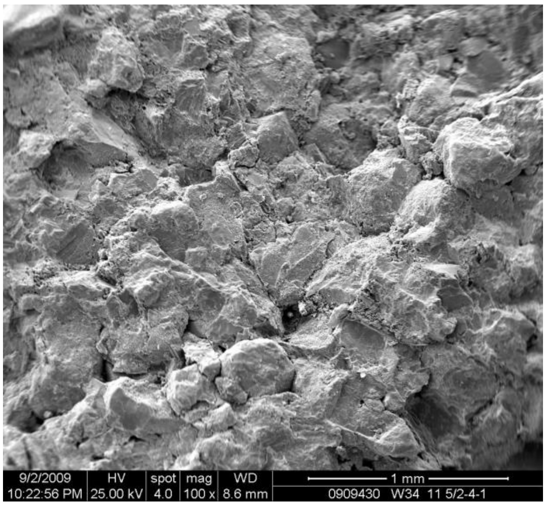
Primary pore(%)		Secondary pore(%)		
Micropores in the crystal	Intergranular pores	Intergranular pores	Corrosion pore in the grain	Mold pore
0.14	0.24	3.95	0.46	0.74



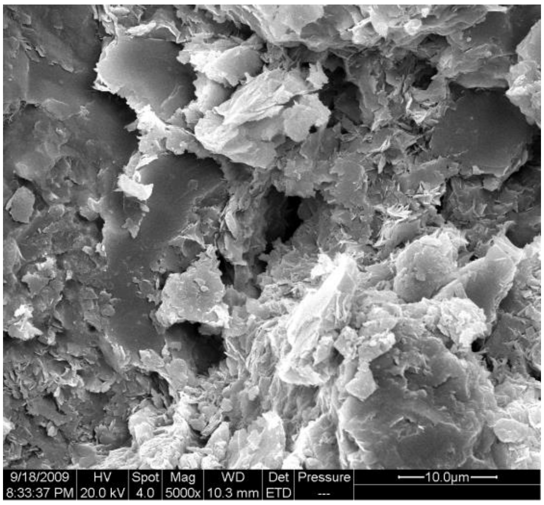
(a) Intergranular pore



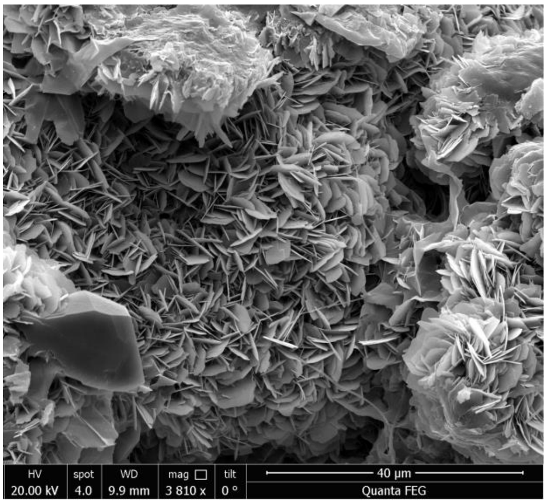
(b) Intragranular corrosion pore



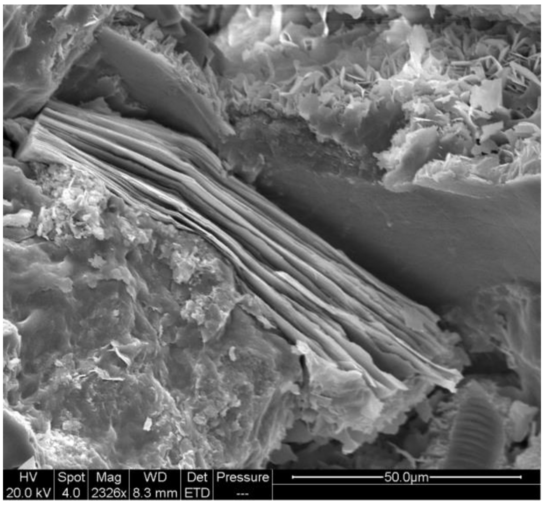
(c) Intergranular pore



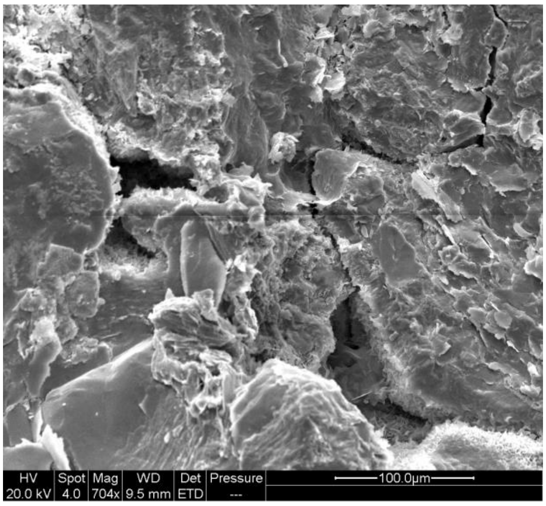
(d) Intergranular pore



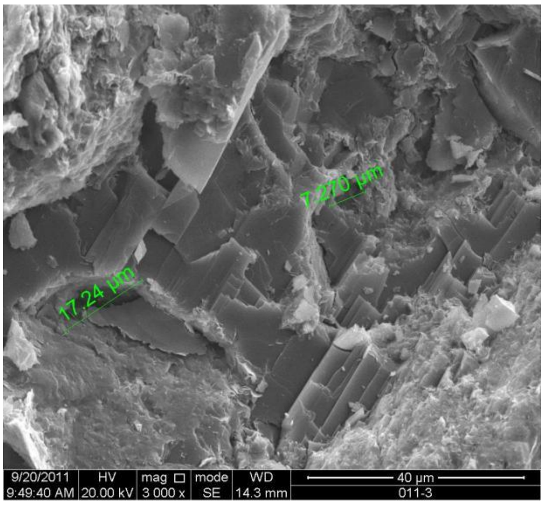
(e) Chlorite adheres to the surface of the particle



(f) Oriented arrangement of mica



(g) Corrosion pore offeldspar



(h) Corrosion pore offeldspar

Fig.6 Study on the characteristics of Chang 2 reservoir under microscope

In this study, the mercury pressure method was chosen to study the pore structure, which can quantitatively describe the pore structure characteristics of the reservoir. Through the experimental analysis of conventional mercuric pressure test, the parameters of Chang2 reservoir were obtained: the average median pressure was 0.648MPa, the discharge pressure was 0.081MPa, the pore throat sorting was poor, the sorting coefficient was 3.04, the coefficient of variation was 0.33, the skewness was 0.387, and it belonged to the type of medium pore with medium coarse throat (Table 5). The pore throat structure of the Chang22 reservoir is poor. Among them, the average mean pressure of Long 22 is 6.21 MPa, the discharge and driving pressure is 1.20 MPa, the maximum pore throat radius is 7.98μm, the average pore throat radius is 1.18μm, the sorting coefficient is 1.25, the coefficient of variation is 1.2, and the skewness is 2.04. The average pore diameter of the sandstone reservoirs in this area is generally between 60 and 88μm, with an average of 73.7μm, mainly showing medium porosity. The average throat radius is generally between 0.03 and 2.89μm, with an average of 1.18μm, most samples are between 1.0 and 3.0μm, followed by <0.2μm, and only a small number of samples are in the range of 1.0-0.5μm, so the range is mainly characterised by medium and fine throats[8].

Table 6. Reference standard for grading pores and throats of sandstone reservoirs

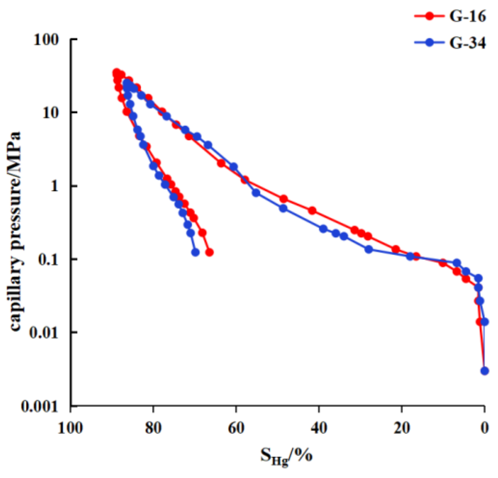
Pore level	Mean aperture(μm)	Throat grade	Mean laryngeal radius(μm)
macropore	>80	Thick throat	>3
mesopore	80~50	Medium and fine throat	3.0~1.0
fine pore	50~10	fine throat	1.0~0.5
pinhole	10~0.5	tiny throat	0.5~0.2
micropore	<0.5	microthroat	<0.2

By analysing the data of 40 blocks of Hg pressure analysis, the capillary pressure curves can be divided into three types:

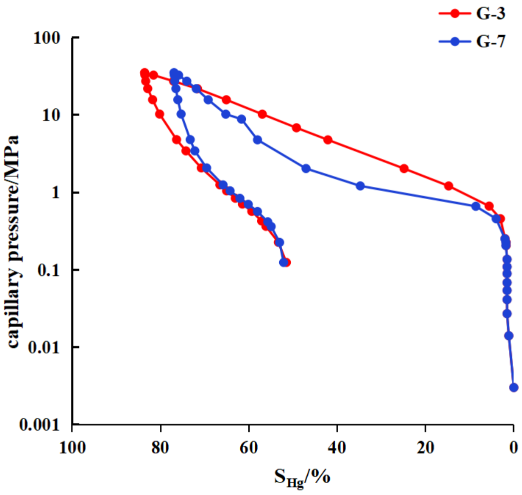
(1) Small pore-medium fine-throat type-medium pore-medium fine-throat type: the average permeability is 3.69×10-3μm2, the average porosity is 14.98%, the average discharge and driving pressure is 4.07MPa, the average mean pressure is 19.44MPa, the average mean radius is 0.42μm, and the average throat radius is 1.29μm.

(2) Fine pore-micro-throat type: porosity and permeability are the smallest, with average values of 8.38% and 0.12×10-3μm2, respectively; discharge pressure and median pressure are the largest, with average values of 4.07MPa and 19. 43MPa, respectively; pore throat radius is the smallest, with mean throat radius and median throat radius of 0.07μm and 0.04μm, respectively, and maximum throat radius of up to 0.22μm, respectively.

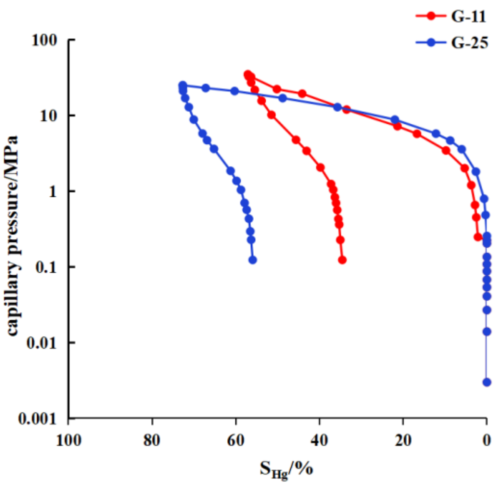
(3) Mesoporous-coarse throat type: The samples showed large permeability and porosity, with average values of 10.03×10-3μm2 and 17.01%, respectively, and the smallest outflow pressure and mean pressure, with average values of 0. 05MPa and 1.14MPa, respectively, and the largest pore throat radius, with mean and median throat radii of 2.28μm and 0.75μm, respectively, and the largest throat radius was up to 16.01μm on average.



(a) Medium pore - thick throat type mercury injection curve



(b) Mercury injection curve between small hole and middle hole and middle throat



(c) Fine pore - fine throat type mercury injection curve

Fig. 7 Classification of mercury injection curve in Chang 2 reservoir

4. CONCLUSION

(1) The Chang2 layer of the GQ block is a braided fluvial deposit, dominated by greyish-white fine-grained feldspar and medium-fine feldspar sandstone, followed by medium-grained, very fine-grained, fine- to medium-grained feldspar, fine-grained calcareous feldspar, medium-grained feldspar and fine-grained rocky feldspar sandstone with mud conglomerate, and dominated by calcite and chlorite cementation, which is well sorted out. Chang2 reservoir has typical characteristics of low porosity and low permeability reservoir, the pore types are mainly rock dissolution holes and intergranular holes, locally visible microcracks and cast holes, the reservoir is inhomogeneous and strong.

(2) According to the mercury pressure coefficient and the characteristics of the mercury pressure curve, the reservoir is classified into 3 types: small pore-medium fine-throat type-medium pore-medium fine-throat type, fine pore-micro fine-throat type, and medium pore-coarse-throat type. In the study area, most of the reservoirs in Chang2 are Small pore-medium fine-throat type-medium pore-medium fine-throat type, accounting for 50 per cent of the reservoirs, while fine pore-micro-throat type accounts for 34.7 per cent of the reservoirs and the mesoporous-coarse throat type for 15.3 per cent of the reservoirs.

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